Environmental Science

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Sangeeta Baksi *Editors*

Socio-economic and Eco-biological Dimensions in Resource use and Conservation

Strategies for Sustainability

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Foreword

In the context of global climate change scenario, conservation and rational use of ecological and biological resources needs to be prioritized for sustaining the environment. The *United Nations Framework Convention on Climate Change* (UNFCCC) states that “Adverse effects of climate change” means changes in the physical environment or biota resulting from climate change, which have significant deleterious effects on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare.

The knowledge of ecological, biological and social dimensions of climate change from a sustainable and equitable development perspective is plausible, if interdependent approach adopted within a unified framework. Evidence influences the anthropogenic warming at a global scale resulting in a cause and effect relationship of resource use. These necessitate for undertaking fundamental and basic research at micro-level for understanding the dynamics of environmental changes in the society.

The present edited volume by distinguished experts with a blending from the discipline of natural, biological and social sciences is very unique and timely contribution in the field of climate change and its effect in the society. All the 26 chapters in the volume depicted the emerging and typical issues concerning the climate change and eco-biological and social contexts. Most of the chapters relate to the studies which are conducted with case studies and particular experiment. These studies have thrown new light on the possibilities and potentials of adaptability to climate change vulnerability which can be utilized for the benefit of the society at large. I am sure the present volume will be a landmark publication in the domain of socio-economic and eco-biological dimensions of climate change and its vulnerability.

I convey my congratulations to the editors of the book and writers of the chapters. I wish the editors all the best in their productive endeavours in the field of climate change issues.

November 2019

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Contents

Socio-Economic and Eco-Biological Dimensions in Resource Use and Conservation: Prologue 1
Niranjan Roy, Shubhadeep Roychoudhury, Sunil Nautiyal, Sunil K. Agarwal and Sangeeta Baksi

Climate Change Impacts and Implications: An Indian Perspective 11
Gajendra Kumar, Rima Kumari, B. S. P. C. Kishore, Purabi Saikia, Amit Kumar and M. L. Khan

Local Socio-Economic Dynamics Shaping Forest Ecosystems in Central Himalayas 31
Shalini Dhyani and Deepak Dhyani

Forest Resources of Jharkhand, Eastern India: Socio-economic and Bio-ecological Perspectives 61
Rahul Kumar and Purabi Saikia

Traditional Agroforestry Systems of Northeast India 103
Sourabh Deb

Agrobiodiversity in Northeast India: A Review of the Prospects of Agrobiodiversity Management in the Traditional Rice Fields and Homegardens of the Region 117
Tapasi Das and Ashesh Kumar Das

Medicinal Plant Biodiversity in India: Harnessing Opportunities for Promoting Livelihood and Food Security 135
Sunil Nautiyal, K. C. Smitha and Harald Kaechele

Plant Diversity and Distribution Pattern in Tropical Dry Deciduous Forest of Eastern Ghats, India 171
Durai Sanjay Gandhi and Somaiah Sundarapandian

Herpetofaunal Diversity and Conservation Status in Amchang Wildlife Sanctuary of Assam, India 217
Jayaditya Purkayastha, Shubhadeep Roychoudhury, Bhim B. Biswa, Madhurima Das and Saibal Sengupta

A Preliminary Checklist of Herpetofauna Occurring in Rowa Wildlife Sanctuary, Tripura, India 225
Jayaditya Purkayastha, Nazruddin Khan and Shubhadeep Roychoudhury

Biology, Uses and Conservation of *Trillium govanianum* 235
Harsh K. Chauhan, Indra D. Bhatt and Anil K. Bisht

Assessment of Different Aspects of Elephant Depredation at a Rural Society-Protected Area Interface in Northeast India Based on Public Estimation 249
Himangshu Dutta and Animekh Hazarika

Exploring Synergistic Inter Linkages Among Three Ecological Issues in the Aquatic Environment 265
Himangshu Dutta

Wildlife Conservation Perspective of Fringe Villagers and Their Socio-economic Dependency: A Case Study from Borail Wildlife Sanctuary, Assam, India 287
Simmee Das, Shubhadeep Roychoudhury, Madhurima Das, Hilloljyoti Singha, Abhijit Das, Niranjan Roy and Sunil Nautiyal

Carbon Sequestration Potential of Trees in Kuvempu University Campus Forest Area, Western Ghats, Karnataka 303
Jogattappa Narayana, Shashidhar, Appaji Nanda and Malve Sathisha Savinaya

Biodiversity and Conservation: India's Panoramic View 313
Leepica Kapoor and S. Usha

Impact of Weather Shock on Food Insecurity: A Study on India 333
Raju Mandal and Munmi Sarma

Statistical Modelling and Variable Selection in Climate Science 351
Shalabh and Subhra Sankar Dhar

Climate Change and Adaptation Strategies in the Gir Kesar Mango Region of Gujarat 379
N. Lalitha

Spatial Shift in Chickpeas in India 399
B. Abirami and Parmod Kumar

Livelihood Strategies and Agricultural Practices in Khonoma Village of Nagaland, India: Observation from a Field Visit 425
Niranjan Roy, Avijit Debnath and Sunil Nautiyal

Transitional Peri-urban Landscape and Use of Natural Resource for Livelihoods 435
Mrinalini Goswami and Sunil Nautiyal

Emerging Technology Intervention Model of Core Support for Inclusive Rural Growth: Social–Economic–Ecological Interface Building Through Innovative Scalable Solutions and Effective Delivery Mechanism 459
Sunil K. Agarwal

Role of Major Forest Biomes in Climate Change Mitigation: An Eco-Biological Perspective 483
Javid Ahmad Dar, Kothandaraman Subashree, Najeeb Ahmad Bhat, Somaiah Sundarapandian, Ming Xu, Purabi Saikia, Amit Kumar, Ashwani Kumar, Pramod Kumar Khare and Mohammed Latif Khan

Climate Change Impact on Eco-biology and Socio-economy—A Concise Discussion 527
Subhankar Chatterjee and Ankit Tandon

Socio-economic and Eco-biological Dimensions in Resource Use and Conservation: Epilogue 547
Niranjan Roy, Shubhadeep Roychoudhury, Sunil Nautiyal, Sunil K. Agarwal and Sangeeta Baksi

Socio-Economic and Eco-Biological Dimensions in Resource Use and Conservation: Prologue

Niranjan Roy, Shubhadeep Roychoudhury, Sunil Nautiyal, Sunil K. Agarwal and Sangeeta Baksi

Abstract Overexploitation of natural resources coupled with anthropogenic climatic variations has put the ecosystem services under enormous pressure not only at macro levels but also at micro levels thereby presenting challenges in social, economic, ecological and biological fronts. Sustainable use of natural resources and their conservation strategies require interdisciplinary and transdisciplinary thinking. The threat is especially severe in regions where people's livelihoods depend largely on natural resources. The objective of this book is to translate the body of scientific knowledge for proper conservation of natural resources and biodiversity in India's sensitive eco-regions and use them sustainably in the interest of our future generations. It may contribute effectively to suggest possible roadmap as well as strategies to address livelihood issues locally and globally while ensuring inclusive growth and social inclusion at large.

Keywords Ecosystem services · Fragile ecosystems · Marginalized communities · Rapid population growth · Landuse changes · Natural disasters

Overexploitation of natural resources coupled with anthropogenic climatic variations has put the ecosystem services under enormous pressure not only at macro levels but

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also at micro levels (MA 2005). The pace and pattern of the changing climate is not only resulting in degraded ecosystems but also threatening to severely test mankind's ability to adapt to them thereby presenting challenges in social, economic, ecological as well as biological fronts (IPCC 2014). Ability of marginalized communities living in susceptible areas to cope up depends on the internal structure of their social systems (Raju et al. 2017). Differential vulnerabilities of individuals, groups and societies vary according to the characteristics of the area which may be understood better in terms of the socio-economic engagements (agriculture, industry, tourism, transport, consumption, lifestyle), eco-biological (evolution of flora and fauna, living condition of populations, territory) and cultural (values and perceptions of trends on conservation and sustainability) indicators acting as a catalyst for the development of holistic and comprehensive plans for adaptation to climatic changes for sustainable use and conservation of natural resources (Lopez and Pardo 2018).

Factors such as land use changes and anthropogenic emissions of green house gases over the last two hundred years are new causes for concern (IPCC 2007). Surface temperature of earth is projected to rise over the 21st century with a higher frequency and longer duration of heat waves as well as occasional cold winter extremes. The ocean will continue to warm and acidify, and global mean sea level will rise. This unprecedented scale of climatic variation poses a great threat to natural resources globally making the environmental, human and financial cost unbearable (UN 2014). It has the potential to manifest at multiple levels impacting multiple sectors not only by intensifying existing risks but also by generating additional risks for natural and human systems (IPCC 2014). At the regional level, rise in temperatures in the Arctic increases the wildfires causing loss of tree cover in Arctic and sub-Arctic forests, whereas at more moderate latitudes shifting rainfall patterns affect land use, water and food security. Arid and semiarid conditions also expand northward making agriculture more difficult at low latitudes. At local levels, changing weather and precipitation patterns can increase large scale flooding and possibly droughts and storms (Emanuel 2005), affect agricultural potential posing a challenge to food and water security (Milly et al. 2002), influence household practices and vector borne diseases, including secondary affect such as desertification, famine and conflicts (Gupta et al. 2007; IPCC 2007; Harris 2018).

Population growth has a direct influence on depletion of natural resources. Due to environmental variability, natural resources are compromised and are already shrinking. Rapid population rise has a negative impact on human development, provision of essential services and poverty alleviation. It also causes a significant increase in demand often leading to mismanagement of key resources (Stephenson et al. 2010). In fact, the scale of the human footprint has grown to the extent that human economic activity has the power to influence major planetary systems. An expected rise in global population by more than 2 billion people between 2010 and 2050 will put additional pressure on the natural resources that are finite. Rapid population growth also generates vast quantities of non-biodegradable waste, drives deforestation and produces massive amounts of CO_2 thereby putting enormous pressure on key natural resources, such as clean air, water, fuel, soil fertility, weather, and myriad ecosystem services. Increased rate of consumption tend to use the resources quicker than their rate of regeneration (Stephenson et al. 2010; Krauss and Kastning 2016). The impacts will be magnified because the increased population will be located primarily in cities, often in low-lying areas sensitive to storm surges and floods, in vulnerable agricultural areas, and in vulnerable eco-regions. Furthermore, current patterns of energy and natural resource use, agricultural practices, and urbanization appear to be largely unsustainable and may lead to increased economic, social, and environmental costs and decreased productivity (Steer 2014).

Very often, global environmental change has been linked to high consumption in developed countries, while its estimated impact is greatest on people in the developing world. The poorest people in vulnerable regions of the world are at severe risk (Stephenson et al. 2010; Feulner 2015), thereby necessitating safeguarding of rural livelihoods and ensuring sustainable development (Agarwal et al. 2019). Such people may be forced to migrate to areas that are environmentally marginal thus leaving them more vulnerable and more likely to exploit new resources in an unsustainable way. This, in turn, may lead to a vicious cycle of poverty and degradation weakening the capacity of poor communities to adapt (Stephenson et al. 2010). In essence, previous and future variations in climate predispose a huge portion of global population in the developing nations to major threats (Feulner 2015).

Research is urgently needed at micro level to come up with adequate strategies for sustainable conservation of key resources and biodiversity without depleting the natural resource base. Issues such as the contribution of population growth, migration, urbanization, and household composition need proper understanding and clarification. Important questions that deserve scientific investigation include proper recording and detailed examination of adaptation approaches of people, investigation of the mechanism of impact of demographic factors (e.g. growth rates, composition, spatial distribution and education levels) on their coping ability, analysis of the influence of fast growth of population and rapid industrialization in sensitive eco-regions (e.g. population structure, water availability, food and shelter requirements and labour markets). Mapping characteristics of migrant flows, including seasonal patterns, duration and destination to aid adaptation strategies, mapping availability of water according to spatially vulnerable groups over time form important aspects in order to identify adaptation strategies, and contribute effectively to UN-Sustainable Development Goals by 2030 (SDG 2015). Study of the impact of population pressure on equity and distribution of water and agriculture is imperative for developing strong measures of vulnerability (Stephenson et al. 2010; Kattumuri 2018).

India is a mega-diverse country in terms of both biodiversity and people. The mountainous region covers an area close to 100 million hectares, arid and semi-arid zones are spread over 30 million hectares and the coastline is about 8000 km long (MoEFCC 2009). It represents 2 'realms' (the Himalayan region represented by Palearctic realm and the rest of the sub-continent represented by Malayan realm), 5 biomes (tropical humid forests; tropical dry deciduous forests, including monsoon forests; warm deserts and semi-deserts; coniferous forests; alpine meadows), 10 biogeographic zones and 27 biogeographic provinces. With only 2.4% of the global land area, India is home to 7–8% of all species recorded, including plants (over 45,000 species) and animals (over 91,000 species) (IUCN 2019). Although

India ranks 10 among the countries with the largest forest cover (FAO 2010), forest distribution remains highly variable, with most located in the central and north eastern states (FSI 2011). Of the 34 globally identified biodiversity hotspots, India harbours four hotspots—Himalayas (entire Indian Himalayan region and that falling in Pakistan, Tibet, Nepal, Bhutan, China and Myanmar), Indo-Burma (entire north east India except Assam, and that of Myanmar, Thailand, Vietnam, Laos, Cambodia and southern China), Western Ghats and Sri Lanka (entire Western Ghats of India and Sri Lanka), and Sundaland (Nicobar group of islands plus Indonesia, Malaysia, Singapore, Brunei and Philippines) (BSI 2016). Over 130,000 species of plants and animals have already been documented from India. The richness of the biodiversity is largely due to the occurrence of species, genetic and ecological variabilities in different bio-geographically and bio-climatically defined zones formed by a wide range of ecosystems and habitats such as forests, grasslands, wetlands, coastal and marine ecosystems, and deserts owing to the varied edaphic, climatic and topographic conditions (Khandekar and Srivastava 2014).

Owing to the location in the eastern Himalayan periphery, India's north east, endowed with rich natural resources has been identified as sensitive to water-induced disasters, fragile geo-environmental settings and underdevelopment in terms of economy. The region's powerful hydrological and monsoon regime, particularly the Brahmaputra and the Barak river systems serve as a resource as well as a source of vulnerability. In comparison to other Indian states with similarity in terms of average per-capita income, India's north east has registered higher incidence of poverty. Environmental sustainability of this region is also affected by growing population and declining productivity of land coupled with comparatively greater dependence on forests and other natural resources (Das 2009; INCCA 2010). Land use change is also considered as an important driver of change in tropical regions either singly or in combination with others (McNeely et al. 1990). About 51.09% of India's land are cultivated, 21.81% forested and 3.92% under pasture, where as 12.34% is occupied by built up areas and uncultivated land, and 5.17% is uncultivated waste. The rest comprises of other types of land (IWP 2009). Large-scale alteration of the landscapes for economical, industrial and infrastructure development and consequent habitat degradation, fragmentation and depletion are considered to be the prime causes of biodiversity loss in tropics. In India's north east, clearance of forests for cultivation including agriculture, tea, coffee, rubber as well as the slash and burn mode of '*jhum*' cultivation wherein the cycle is ever reducing, modification of main natural habitat for industrial and developmental activities (oil and natural gas, coal mining, construction of roads etc.), forest fire and other anthropogenic activities have been significant drivers of change. In the absence of effective land use policy, as large as 2 million hectares of land in India's north east has been affected by '*jhum*' cultivation (Tripathi et al. 2016). Hence, vulnerability of fragile forest ecosystems of north eastern India is perceived to pose a variety of stress on sustainability of livelihood system of the poor inhabitants through stresses on ecosystem function (Bujarbarua and Baruah 2009). The eastern Himalayas is also likely to expect major transformations in biodiversity across all systems (terrestrial, freshwater) and all levels (genetic, species, ecosystem), which is triggered by the speedy erosion of the ecological balance in the flow of material and energy (ICIMOD 2010). A recent study has ranked the north eastern state of Assam to be the most vulnerable, followed by Mizoram, Manipur, Meghalaya, West Bengal, Nagaland, Tripura, Arunachal Pradesh and Sikkim (NMSHE and SDC 2019).

In India, more than 57% people are dependent on agriculture and forestry sectors for their livelihood. In 2017, a parliamentary committee in its report submitted to India's Agriculture Ministry noted that extreme weather events are costing the country annually USD 9–10 billion, and is likely to impact agricultural productivity with increasing severity from 2020 to the end of the century (Mohan 2017). According to a 2018 UN report, India suffered a massive loss of USD 79.5 billion due to extreme weather events in the past 20 years (The Hindu 2018). A World Bank report published in 2018 warned that with possible 1–2% rise in annual average temperature, the living standards of nearly half of India's population will be lowered by 2050 costing up to 2.8% of the country's GDP (World Bank 2018). According to last year's IPCC report, the impact of climatic variations could be distressing for India both socially and politically particularly because of its large population and magnitude of inequality and poverty. The estimated rise in global temperatures could affect the underprivileged and vulnerable populations through food insecurity, income loss, adverse health impacts, population displacements etc. (Awasthi 2018). A recently published Stanford study reported that between 1961 and 2010 global warming has caused the Indian economy to be 31% smaller than it would otherwise have been, and the shrinkage in wealth per person in the world's poorest countries has been 17–30% (Economic Times 2019). A 2019 report by the International Labour Organization projected India to incur a loss of 5.8% working hours in 2030 due to global warming, particularly affecting agriculture and construction sectors, which is equivalent to a productivity loss of 34 million full-time jobs (The Hindu 2019).

There is a probable link between increased variability in Indian monsoon rains and natural disasters. Uneven increase in temperature has been associated with driving more energy into local, regional and sub-continental climate systems thereby amplifying climate alterations and frequency as well as severity of extreme weather events. Human encroachment and heavy siltation in river beds and other water bodies have exacerbated the flood risks (Mishra 2014). Studies suggest noted rise in frequency and extent of landslides in India, particularly in the Himalayas and the Nilgiris (Sati et al. 2011; Ganapathy and Hada 2012). During June 2013, thousands of people were drowned, dozens of bridges tore apart, miles of paved roads swept away and herds of livestock carried off in one of the most disastrous floods in recent memory in the Himalayan settlement of Kedarnath. Researchers believe that melting of glaciers and shifting of storm tracks have played major roles behind this calamity apart from commonly reported causes, such as poorly built homes, and unregulated development along the river (Grossman 2015). During November–December 2015, an extreme pluvial flooding, following a heavy and unusual rainfall, occurred in Chennai and its surroundings and caused severe damages to the properties, infrastructure, livelihood, health and environment besides taking away hundreds of precious lives. Researchers found a relation between the onset of the atmospheric weather change and the swarms of 8th to 9th November 2015 in the Indian Ocean region and associated thermal radiation, and indicated that the great pluvial flood disaster in Chennai and its surroundings was a resultant of the swarms in the north Sumatra oceanic region (Akilan et al. 2017). Again in July–August 2018, 42% more rain than expected during the monsoon months of July and August caused a shift in the behaviour of Periyar river and its basin in Kerala state of India which the landscape could not adjust causing the worst flooding in nearly a century. Hundreds of people died, and at least a million had to be evacuated whereas thousands of cattle, calves, buffaloes, goats, dogs also lost lives (NDMA 2018; Vijayan 2018). As per the records of India's Ministry of Environment, Forest and Climate Change, extreme weather events have taken away as many as 2405 human lives in the year 2018 alone (The Weather Company 2019). As such, climate variations has been recognized as a risk multiplier that disproportionately burdens the poorest and most vulnerable as evident from some of the natural disasters cited as above. Therefore, possible aversion, adaptation and mitigation of extreme natural events necessitate the immediate understanding of the footprints of climate change over natural disaster profile (Sami et al. 2016).

For instance, various climate models used to predict the macro- and meso-level scenarios have not been validated at local level in order to understand their practical implementation (Nautiyal 2011). In comparison to macro level studies, there is considerable gap in data so far as micro level studies are concerned. Very strong and dynamic case studies are also lacking at micro level. But, for effective and informed planning at the macro-level, a better understanding of micro-level perception is imperative (Singh et al. 2018). But, several models predicting national and regional level scenarios do not usually consider micro variables such as environmental resources, socio-economic factors and policy aspects, including land availability, local climatic conditions, labour and capital, subsidies, nature conservation strategies etc. This micro-macro paradox indicates that even if affirmative action works and achieves direct impact, yet the changes might seem unstoppable (van der Berg 2011). This is the case for the historical loss of biodiversity that is now increasingly seen as a human caused mass extinction, and for the increasing pollution of our environment with chemical substances, which endanger human health and the health of our habitat (van den Berg and Cando-Noordhuizen 2017). In particular, micro level research needs to be undertaken in relation to biodiversity, health, natural resource management, land use and land cover development, adaptation and the development of socio-ecological systems for facilitating holistic adaptation and mitigation activities (Nautiyal 2011). In this process, it becomes imperative to connect knowledge institutions with field based developmental agencies to address such challenges with local institutional arrangements by empowerment and imparting skills to local communities with appropriate and scalable technological interventions and strong social engineering component (Agarwal 2013).

Sustainable use of natural resources and their conservation strategies require interdisciplinary and transdisciplinary thinking (IPCC 2014; Feulner 2015). In this endeavor and to address the above issues and challenges, contributions were invited for present knowledge product from stakeholders, scholars, policy makers, academia and students cutting across the disciplines to portray a large variety of theoretical and actual research on resource use, conservation and related developmental issues in sensitive and vulnerable eco-regions of India. The threat is especially severe in regions where people's livelihoods depend largely on natural resources. The objective of this book is to translate the body of scientific knowledge for proper conservation of natural resources and biodiversity and use them sustainably in the interest of our future generations. Thus, it may contribute effectively to suggest possible roadmap as well as strategies to address not only conservation and livelihood issues locally and globally, but also to ensure inclusive growth and social inclusion at large.

The volume is the outcome of the national workshop on "Agrobiodiversity Conservation and Ecosystem Management" during 4–5 April, 2017 followed by the international conference on "Scientific and Indigenous Bio-cultural Knowledge in Understanding Climate Change in Biodiversity Hotspots to Develop Strategies for Socio-ecological Development: Data Availability, Requirement and Gaps" during 27–28 July, 2017 held in Assam University, Silchar (AUS). These events were organized jointly by the Centre for Ecological Economics and Natural Resources (CEENR) of the Institute for Social and Economic Change (ISEC), Bengaluru, and Assam University's Department of Economics and Department of Life Science & Bioinformatics. For these events, financial support was received from various funding agencies, such as (i) Indian Council of Social Science Research (ICSSR), Govt. of India, (ii) Technology Information, Forecasting and Assessment Council (TIFAC), Department of Science and Technology, Govt. of India, (iii) Ministry of Development of North Eastern Region, Govt. of India, and (iv) Science and Engineering Research Board, (SERB), DST, Govt. of India. Hon'ble Vice Chancellor of Assam University Prof. Dilip Chandra Nath inaugurated the events and scholars from academic institutions in India and abroad have participated and presented papers in these events. We take this opportunity to express deep, sincere and whole-hearted thanks and gratitude to the funding agencies for giving us the privilege to organize the events in Assam University, Silchar in association with CEENR, ISEC, Bengaluru, India which culminated into this volume. Since the topic of this volume is highly interdisciplinary therefore, scholars from Indian Institute of Technology Kanpur (IIT) Kanpur; G.B. Pant National Institute of Himalayan Environment & Sustainable Development (GBPNIHESD), Almora; Gujarat Institute of Development Research (GIDR), Ahmedabad; Institute for Social and Economic Change (ISEC), Bengaluru; CSIR-National Environmental Engineering Research Institute (CSIR-NEERI), Nagpur; Central University of Jharkhand, Ranchi; Pondicherry University, Puducherry; Department of Science and Technology, New Delhi were invited to contribute chapters on their grounded research work for publication in this volume. We extend our sincere thanks to all the paper contributors who made presentations during the academic events held in Silchar and authors from invited papers for their contribution for publication in this volume.

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Climate Change Impacts and Implications: An Indian Perspective

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Abstract Climate change is one of the most complex global environmental problems, impacting the physical and biological systems of aquatic, terrestrial and marine environments. India is among one of the most vulnerable countries that has already been experiencing changes in climate and the impacts of climate change. Various sectors such as agriculture, forestry, health, socio-economy, etc. have found to be severely affected by the implications of climate change in the country. Significant impacts over the forest ecosystems, global biodiversity and ecosystem integrity have also been observed in recent days. Apart from reduction in forest productivity, a shift in the forest type boundaries along altitudinal and rainfall gradients have been found. Loss of sea ice, rapid warming, and higher organic inputs affect marine and lake productivity, while combined impacts of wildfire and insect outbreaks decrease forest productivity. All these emerging uncertainties due to climate change have found to aggravate the problems of future food security within the country. Despite putting numerous efforts to mitigate the effects of climate change, India has failed in responding sufficiently in dealing the issue of climate change. Thus, it is imperative to come up with more effective adaptation and mitigation strategies in order to combat the effects of climate change.

Keywords Climate change · Implications · Adaptation · Mitigation

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Abbreviations

TRMM	Tropical Rainfall Measuring Mission
AVHRR	Advanced Very High Resolution Radiometer
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
ERS	European Remote Sensing
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
MODIS	Moderate Resolution Imaging Spectroradiometer
SMOS	Soil Moisture and Ocean Salinity
SPOT	Satellite Pour l'Observation de la Terre, "Satellite for observation of Earth"
SARAL	Satellite with ARgos and ALtiKa
ALOS PALSAR	Advanced Land Observation Satellite Phased Array type L-band Synthetic Aperture Radar
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
NISAR	NASA-ISRO Synthetic Aperture Radar
JERS	Japanese Earth Resources Satellite
RISAT	Radar Imaging Satellite
ENVISAT	Environmental Satellite
IRS	Indian Remote Sensing
UNFCC	United Nations Framework Convention on Climate Change

1 Background

Climate change is the prime issue in global warming and global environment due to its associated vulnerability and biodiversity loss (IPCC 2007). UNFCCC (1992) has defined climate change as *the change that can be attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*. India is among one of the countries that has been predicted to be impacted severely due to climate change in the near future because of its diverse physiographic conditions and exploitation of natural resources at rapid pace (Puthucherril 2012; Saha and Talwar 2010). Climate change has profound impacts on the physical and biological systems of aquatic, terrestrial and marine environments (Lolaksha and Anand 2017). The effect may be direct on crop yield due to a change in temperature and increased pest populations or indirect such as damage to agricultural crops caused by the increased frequency of coastal flooding due to sea-level rise (IPCC 2007). Climate change stands to alter ecosystem structure and function through numerous and diverse pathways (Post 2013).Changing the water availability, CO_2 concentration, tropical storm activity, accelerated sea-level rise, increasing sea surface and atmospheric temperature, variability in the timing and quantity of precipitation and littoral erosion are the critical factors affecting the ecological integrity of coastal ecosystems as well as important societal activities (Day et al. 2013; Yañez-Arancibia 2015). Climate change is expected to alter the behavior and life history characteristics of organisms which could lead to dramatic changes in inter and intra-specific competition, predation, mutualisms, species distributions, biodiversity patterns, and the provisioning of ecosystem services (Tylianakis et al. 2008). In the long-term, climate change will most likely alter the littoral zone, the species composition and biodiversity of coastal areas, and important ecosystem services such as nutrient cycling, primary and secondary productivity (Walther et al. 2002; Day et al. 2013). Climate change along with habitat fragmentation is one of the major threats to biodiversity and these changes have adverse and irreversible impacts on various ecosystems services which are ultimately going to affect the social, cultural and economic conditions of the human society (Bharali and Khan 2011). Most of the climate change research have tended to examine climate effects on biotic components by focusing on single species while treating the larger community as background variation (Jamieson et al. 2012) and by typically focusing on a single climate variable at a time (Todgham and Stillman 2013). The present study discussed the impacts and consequences of climate change over various sectors including agriculture, biodiversity, mangroves, coastal and forests ecosystems.

2 Impacts of Climate Change

Climate change is one of the most critical environmental issues that have grabbed the attention of the whole world. India is facing an alarming environmental and socio-economic challenge in its effort to protect its fast depleting natural resources (Lolaksha and Anand 2017). Coastal ecosystems, biodiversity, water, human health, energy, transportation, forests, and agricultural productivity are some other important sectors that will be subjected to the maximum exposure to climate change (UNFCCC 2006; National Research Council 2013). Climate change will have a profound impact on human and ecosystems during the coming decades through variations in global mean temperature and precipitation pattern. The main culprit behind the changes in the climatic conditions is believed to be the effects of human interference (Santer et al. 2013).

3 Impacts on Agriculture and Agricultural Productivity

The agricultural productivity is under direct influence of climate change and any change in the temperature, precipitation pattern and CO_2 concentration are certainly prospected to affect the crop productivity (Kumar and Gautam 2014). Climate change impacts agricultural productivity mainly in two ways: first, directly through changes in temperature, precipitation and CO_2 concentration and second, indirectly through changes in soil, distribution and frequency of infestation by pests, insects, diseases or weeds (Chatterjee 2003). The growth, development, water use efficiency and yield of crop are mainly dependent on weather during their growing seasons. Any deviation from the normal weather will ultimately affect the efficiency of applied inputs as well as impair the food production (Mall et al. 2007). With the changes in the climate, adjustments and adaptations are required to current practices in order to maintain the productivity, while in some cases the optimum type of farming changes (Gornall et al. 2010). The severity of climate change impacts on the agricultural productivity depends on the degree of adaptation at the farm level, farmers' investment decisions and policy choices (Kahil et al. 2015). Agriculture in India is hindered due to small landholdings, inadequate resources and lack of agro-technological information. The broad objective of sustainable agriculture is to balance the inherent land resources with crop requirements, paying special attention to optimization of resource use towards achievement of sustained productivity over a long period (Lal and Pierce 1991). The emerging uncertainties due to climate change are certainly going to aggravate the problems of future food security by exerting pressure on agriculture (Anand and Khetarpal 2015). Agricultural production is highly sensitive to monsoon variability (Chakrabarty 2016). In India, more than 60% of the crop area is mainly rain-fed and rain-fed agriculture is highly vulnerable to change in the precipitation pattern. With the change in the climate, major crops like rice, wheat, maize is going to be affected in India (Chatterjee 2003) and consequently, the food security is going to be adversely affected (Wheeler and Braun 2013; Chakrabarty 2016). Soil quality, water availability or drought stress and climate change are three biophysical factors which need to be addressed for food security in the face of climate change (Lal 2009). It has also been estimated that the *Kharif* crops are going to be affected more by rainfall variability, while *Rabi* crops by minimum temperature (Tesfaye et al. 2017). Agroforestry offers the potential to develop synergies between efforts to mitigate climate change and to help vulnerable populations to adapt to the negative consequences of climate change (Verchot et al. 2007).

4 Impacts on Forests and Forestry Sector

Climate is one of the determining factors of the distribution, structure and ecology of forests ecosystems (Kirschbaum et al. 1996). Climate change has significant impacts over the forest ecosystems, global biodiversity and ecosystem integrity (Ravindranath et al. 2005). In India, changes in the climatic conditions have affected the forests productivity and also a shift in the forest type boundaries along altitudinal and rainfall gradients (Kaushik and Khalid 2011). The shift has been indicated towards wetter forest types in the northeastern region while towards drier forest types in the northwestern region in the absence of human interventions (Ravindranath et al. 2005). The regions that have identified as more vulnerable to climate change include the upper Himalayas, northern and central parts of Western Ghats and parts of central India, while the northeastern forests have been identified as the more resilient ones (Chaturvedi et al. 2010). The major impacts of climate change that on the forests are the disruption of carbon-regulating services, prolonged droughts, more pest invasions and other environmental stresses that would eventually lead to their destruction and degradation (Seppälä 2009). Natural disturbances such as pest and disease outbreaks are going to be affected by climate change which in turn is going to impact the forestry (Alig et al. 2002). Not only the forest fires or insect damage but also a variation in the frequency of extreme events such as strong winds, winter storms, droughts, etc. can bring about a loss to commercial forestry (Kirilenko and Sedjo 2007). Many terrestrial biogeochemical processes, such as soil respiration, litter decomposition, nitrogen mineralization and nitrification, denitrification, methane emission, fine root dynamics, plant productivity and nutrient uptake will be impacted with temperature changes which in turn will alter forests and ecosystem dynamics (Norby et al. 2007). Changes in the structure and functioning of forest ecosystem are going to have negative impacts on the productivity of forest ecosystems which in turn will affect local economies (FAO 2005). The impacts of climate change on forestry include the increasing global timber supply and a slow increment in the demand for forest production (IPCC 2001). Climate change brings an irreversible damage to the forest ecosystems which certainly require the longest response time to adapt (Leemans and Eickhout 2004). With the change in the forest structure and composition, other dependent entities such as wildlife, human systems and economies will face a challenge to keep pace with the rate of change within the forest ecosystem.

5 Impacts on Biodiversity

India harbors a huge variety of biodiversity and, it is under the threat of climate change (Kumar and Chopra 2009; Soni and Ansari 2017). Climate change has been identified as one of the major drivers behind the adverse effects on biodiversity and its associated goods and services (MEA 2005). Climate is one of the most important factors that regulate the growth, abundance, survival and distribution of species (Travis 2003). Climate change has affected the global biodiversity resulting in the extinction of many species of flora and fauna from their natural habitat (Bharali and Khan 2011). The changes in the climatic conditions have found to exacerbate the effects of other anthropogenic factors that threaten the biodiversity (Moore et al. 1999; Forrest et al. 2012). Impacts of climate change over the biodiversity vary from region to region (Sarkar 2012). It is also a major determinant of distribution and abundance of species in both managed ecosystems (agriculture, production forests, cities and many coastal zones) and natural ecosystems (terrestrial and marine) (Perrings 2010). With the shift in the climatic conditions, species with small fragmented populations, or populations restricted to small areas are more vulnerable (Integrated solutions for biodiversity, climate change and poverty 2010). Also, the synergism between the rapid temperature rise and other factors of climate change could disrupt the linkage among the species resulting in reformulation of species communities, differential changes in species and in their extirpation or extinction (Root et al. 2003). Effects of climate change on the natural system may be diverse and range from change in the timing of phenological events of plants to changes in species abundance, distribution, timing of reproduction in animals and plants, animal and bird migration patterns, and frequency and severity of pest and disease outbreaks and shifts in habitat, etc. (Perrings 2010; Bharali and Khan 2011). Apart from these effects, the risk of extinction for already vulnerable species is likely to increase (Thomas et al. 2004) because many species require a particular time period to adapt themselves against the changing climatic conditions (Menéndez et al. 2006).

6 Impacts on Coastal Ecosystems

Human pressure on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, installation of energy generation infrastructure in coastal and marine ecosystems, transportation networks and urbanization (Yáñez-Arancibia 2013, 2015). The analysis and implementation of coastal adaptation toward climate-resilient and sustainable coasts have progressed more significantly in developed countries than in developing countries (Wong et al. 2014). The use of combined approaches to coastal adaptation instead of a single strategy, such as the combination of ecology and engineering, allows for better preparation for a highly uncertain and dynamic coastal environment (Cheong et al. 2013).

The biggest climate change challenge faced by the coastal ecosystem is the rising sea level (McLeod and Salm 2006). The ongoing phenomenon of climate change has been predicted to pose a major threat to the Indian mangroves (Sandilyan 2015). Impacts of climate change on mangroves of coastal areas used to be influenced by various factors including sea level rise, changes in river flow due to changes in snowmelt and precipitation pattern in the catchment, changes in local temperature and in storm surges (Mckee et al. 2012). Sea level rise (SLR) of up to 1 m has been projected for the period 1990–2100 with substantial regional variation (IPCC 2007) and mangroves have been found to be vulnerable to SLR and even a 1 m rise would result in the complete submergence of the mangroves of Sunderbans (Chowdhury and Rob 2007). However, mangroves in low-island coastal regions where sedimentation loads are high and erosion processes low can adapt better. The mangrove forests along the arid coasts, in subsiding deltas, and on many islands have been predicted to decline in area, structural complexity and in functionality along with their continuous expansion towards poles (Alongi 2015).

Climate change has also impacted the coral reefs where the major observed effects include increased mass coral bleaching, declining calcification rates, and a range of other changes to subtle yet fundamentally important physiological and ecological processes (Guldberg 2011). Coral reefs are found to be sensitive and are vulnerable to rise in the sea surface temperature (SST) against their optimal temperature

(Sebastian and Kaaya 2018). Bleaching of coral reefs due to the increase in sea surface temperature (SST) of > 1 °C has been very well known (Kumagai and Yamano 2018). One of the most widespread coral bleaching worldwide, including in the Indian coral reefs, occurred during 1997–98 when SSTs increased by an average of 3 °C in the Indian Ocean in conjunction with a major El Nino event (Sum 2016). It was estimated that the 1997–98 El Niño event alone had caused the bleaching of 16% of the world's coral reefs (World Bank 2007). Enhanced SST during the 1997/98 El Niño event affected the marine ecosystems, including fishery and coral bleaching, while enhanced air temperature affected terrestrial ecosystems, public health and air quality due to the production of photochemical smog under strong sunlight (Sum 2016). Bleaching also sets the stage for other decline in reef health, such as increment in the coral diseases, breakdown of reef framework by bio eroders and the loss of critical habitat for the associated biota (Baker et al. 2008). Increased ocean acidification, via increased absorption of CO_2 by seawater has reduced the capacity of coral reefs to grow and maintain their structure and function (Spillman et al. 2011).

7 Impacts on Human Health

Climate change impacts on health is one of the important determinants for the assessment of total costs of climate change to enhance the understanding of weather and climate's effects on socio-economic sectors (Confalonieri et al. 2007). The health risks associated with climate change are on the rise worldwide (UN 2017) and thereby worsening the existing health threats and creating new public health challenges (NOAA 2016). Changes in the climatic conditions have been predicted to cause more heat stress, an increment in waterborne diseases, poor air quality, extreme weather events and a rise in the transmittance of diseases by insects and rodents (USGCRP 2016) which is ultimately going to impact the human health. Based on the present day sensitivity to heat, an increment of about thousands to tens of thousands in premature heat-related deaths in the summer and a decline in the premature cold-related deaths in the winter has been projected as a result of climate change by the end of the century (USGCRP 2016).

Climate change effects on human health in India are a broad topic, covering areas from extreme weather events to shifts in vector-borne diseases. Floods create conducive environments for numerous health consequences resulting from disease transmission. In South Asia, scientists predict an increased frequency of floods in mountainous regions in the coming days due to greater intensity of rainfall events and glacier lake outburst (Cruz et al. 2007). Floods resulting from monsoon rains killed more than 2000 persons and displaced more than 20 million people in Bangladesh, India, and Nepal during 2007 (Bajracharya et al. 2006). Rising sea-surface temperatures are expected to increase tropical cyclone intensity and the height of storm surges (Ali 1999). Although cyclones originating in the Bay of Bengal and the Arabian Sea have decreased in frequency since 1970, these have increased in intensity, causing significant damage in India and Bangladesh (Lal et al. 2001). Public health effects of cyclones include diseases and illnesses associated with the loss of clean water, hygiene, and sanitation, loss of shelter and belongings, population displacement, toxic exposures, hunger and malnutrition risk due to food scarcity (Keim 2006).

8 Socio-Economic Consequences of Climate Change

The alleviation of poverty and food insecurity has been undermined in the present scenario of changing climatic conditions (Karfakis et al. 2012). Climatic conditions play a major role in influencing almost all aspects of life on earth and in shaping the physical, biological, and socioeconomic environment (Rogers 1994). The impacts of GHG emissions and the resulting climate change have found to influence the global economy significantly (Raman et al. 2012). Agriculture, fisheries and other economic sectors that depend on weather conditions are mostly affected by climate change either directly or indirectly (IPCC 2012). The events of climate change have raised a concern about the threats to current income and consumption patterns of households and individuals that are dependent on these sectors (Foresight 2011; IPCC 2012). Changes in frequency and intensity of extreme weather events may lead to devastating floods (Karl et al. 1996). These extreme climatic events can result in large economic losses through direct damage to infrastructure, property, and agricultural land (Waterton and Wynne 2004). The impacts of climate change can be measured in terms of economic cost particularly associated with the impacts that are linked to market transactions (Smith et al. 2001). The quantitative estimation of the economic damages of climate change is generally based on the aggregate relationships linking average temperature change to loss in gross domestic product (GDP) (Ciscar et al. 2011). Monetary measures of climate change impacts on human health and ecosystems are difficult to calculate (Smith et al. 2001). Prolonged climatic variations have contributed to the collapse of several well-established civilizations at certain times in the past (Weiss et al. 1993). The quantitative assessment of the economic impacts of climate change provides the justification for the strategies to control global warming and minimize detrimental consequences (Ciscar et al. 2011). With the changes in the climate, the impacts on agricultural production, income and health-related effects are expected to rise which ultimately impact the rural livelihood (Karfakis et al. 2012). Climate change adaptation and mitigation are likely to involve policy decisions and investments in infrastructure. The impact of climate change on the society is mainly dependent on the direct or indirect interplay between environment, on the one hand, and health and consumption on the other hand (Karfakis et al. 2012). A society can be benefited only by improving the understanding, assessment, prediction, and early detection of both natural variability and any possible anthropogenic changes that can help towards the insight of a stable climate system (NRC 1998).

9 Role of Geoinformation Science in Climate Change Research

Geoinformation science has provided a new dimension to global climate change research over the past few decades and has significantly been contributing in climate change monitoring through continuously observing remote sensing satellites by providing biological, physical, and chemical parameters on a global scale at varied resolutions (Justice et al. 2002; Gou et al. 2015). A climate change monitoring system is an amalgamation of satellite observations, ground-based data and forecast models to monitor and forecast changes in the weather and climate with reference to historical patterns shift due to frequent and repetitive coverage of earth's environment (Tucker and Sellers 1986). It is widely used to estimate various parameters in the domain of atmosphere, oceanic and terrestrial which has provided major advances in understanding earth system and its climate (Yang et al. 2013). The periodic monitoring of different climate variables is being done by specially designated earth science missions (Table 1). For example, sea surface temperatures (SST) is being monitored by NOAA satellite (Heirtzler et al. 2002), whereas glacier recession, which is the response to climate warming due to their sensitive reaction to even small climatic changes (Lemke et al. 2007), is being monitored by various optical satellite remote sensing satellites (Bishop et al. 2000). The sea surface topography over the open ocean and the study of the ocean circulation is being studied efficiently by powerful

Table 1 Major climatic variables (as per UNFCCC)

Domain	Parameter	Sensors
Atmosphere	Greenhouse gases, water vapour, pressure, precipitation, surface radiation budget, temperature, wind speed and direction, ozone and aerosols	TRMM, NOAA (AVHRR), GOME, GOMOS, ERS, ENVISAT, SCIAMACHY
Oceanic	Sea surface temperature, wind velocities, bathymetry, sea level, ocean colour, coastal processes, sea ice	Oceansat, TRMM, NOAA (AVHRR), Aqua/Terra (MODIS), INSAT (VHRR), SMOSS Aquarius, Jason, ERS, Topex/Poseidon, Landsat, SPOT, IKONOS, SARAL, Megha-Tropiques
Terrestrial	Land use/land cover, river morphometrics, ground water, snow cover, glacier studies, fraction of absorbed photosynthetically active radiation (fPAR), leaf area index (LAI), above-ground biomass (AGB), gross primary productivity, soil moisture, forest fire, desertification, terrestrial biodiversity, and habitat properties	Landsat, Sentinel, SPOT, IKONOS, Resourcesat, Quick Bird, RADARSAT, Aqua/Terra (MODIS), ALOS PALSAR, ENVISAT, TerraSAR-X, SMOS, AVIRIS, JERS, IRS, RISAT, Cartosat

Sources CEOS (2007), NRC (2008), Weng (2011) radar altimetry (Ablain et al. 2009; Le Traon et al. 2001). The impacts of drought can be identified using various vegetation indexes obtained from satellite data (Kogan 1995, 1998; McVicar and Jupp 1998). The precipitation variability at regional to global scale is being studied using TRMM remote sensing (Nicholson et al. 1990; Farrar et al. 1994; Santos and Negri 1997). The amounts and distributions of atmospheric constituents, such as trace gases, aerosols, and clouds has been monitored using passive remote sensing instruments viz., GOME, SCIAMACHY, and GOME-2 (Loyola et al. 2009). The atmospheric variables are being monitored by GOME, GOMOS, TRMM, NOAA (AVHRR), ERS, ENVISAT, SCIAMACHY satellites and able to monitor greenhouse gases water vapour, pressure precipitation surface temperature, concentration of ozone, aerosol concentration etc. (Table 1). The terrestrial variables are being monitored through land use/land cover, river morphometric, ground water, snow cover, glacier studies, fraction of absorbed photosynthetically active radiation (fPAR), leaf area index (LAI), above-ground biomass (AGB), gross primary productivity, soil moisture, forest fire, desertification, terrestrial biodiversity, and habitat properties etc., which are being sensed by LANDSAT, Sentinel, SPOT, IKONOS, Resourcesat, Quick Bird, RADARSAT, Aqua/Terra (MODIS), ALOS PALSAR, ENVISAT, TerraSAR-X, SMOS, AVIRIS, JERS, IRS, RISAT, Cartosat satellites. The Oceanic variables are being monitored through sea surface temperature, wind velocities, bathymetry, sea level, ocean colour, coastal processes, sea ice etc., which are being sensed by Oceansat, TRMM, NOAA (AVHRR), Aqua/Terra (MODIS), INSAT (VHRR), SMOSS Aquarius, Jason, ERS, Topex/Poseidon, Landsat, SPOT, IKONOS, SARAL, Megha-Tropiques satellites. MODIS provides many standard data products that are widely used by scientists for global change studies (Table 2 and Fig. 1). Scopus search with keywords 'MODIS and Climate' showed 4617 results indicating the widespread use of MODIS in climate change research. The major products of the MODIS are briefly listed in Table 2 and selected products are presented in Fig. 1.

10 Climate Change Mitigation and Adaptations

The strategies to curb the implications of climate change do not depend only on the response of the Earth system, but also on how humankind responds through changes in technology, economies, lifestyle and policy (Moss et al. 2010). The challenge of confronting the impacts of climate change is often framed in terms of two potential paths that are adaptation and mitigation. The adaptation strategies are generally defined around the management of unavoidable events; while mitigation aims to avoid the unmanageable events (Laukkonen et al. 2009). Initial efforts at dealing with the problem of global warming were concentrated on mitigation only (UNFCCC 1992). Later, adaptation was also perceived as a viable option in reducing the vulnerability associated with anticipated negative impacts of climate change. It is increasingly realized that mitigation and adaptation should not be pursued as independent entity rather

Table 2 MODIS data products for global change studies

Domain	Product
Atmosphere	Aerosol Product Total Precipitable Water Cloud Product Atmospheric Profiles Atmosphere Joint Product Atmosphere Gridded Product Cloud Mask
Land	Surface Reflectance Land Surface Temperature and Emissivity Land Cover Products Vegetation Index Products (NDVI and EVI) Thermal Anomalies—Active Fires Fraction of Photosynthetically Active Radiation (FPAR)/Leaf Area Index (LAI) Evapotranspiration Gross Primary Productivity (GPP)/Net Primary Productivity (NPP) Bidirectional Reflectance Distribution Function (BRDF)/Albedo Parameter Vegetation Continuous Fields Water Mask Burned Area Product
Cryosphere	Snow Cover Sea Ice and Ice Surface Temperature
Ocean	Sea Surface Temperature Remote Sensing Reflectance Chlorophyll-a Concentration Diffuse Attenuation at 490 nm Particulate Organic Carbon Particulate Inorganic Carbon Normalized Fluorescence Line Height (FLH) Instantaneous Photosynthetically Available Radiation Daily Mean Photosynthetically Available Radiation

Sources Remer et al. (2005), Hall et al. (2002), Zhang et al. (2003), https://modis.gsfc.nasa.gov/data/

as complements of each other (Nyong et al. 2009). Mitigation has been applied successfully in various contexts at the international, national, regional, local and even individual levels. The strategy involves technical and infrastructural investments, renewable energy implementation (to reduce climate change and improve energy security), as well as energy efficiency improvement (Laukkonen et al. 2009). Adaptation strategies require long-term horizons which focus on shorter time frames and quick fixes (Huq et al. 2006). These are more or less dependent on the characteristics of the system of interest, including its sensitivities and vulnerabilities (Smit et al. 2000). The adaptation strategies basically involve developing ways to protect people and places by reducing their vulnerability to climate impacts (UCAR 2011). Unlike mitigation, adaptation is most appropriately implemented at the local level which depends on a variety of factors including climatic and geographic differences, governance systems, housing realities, public infrastructure, resource accessibility,

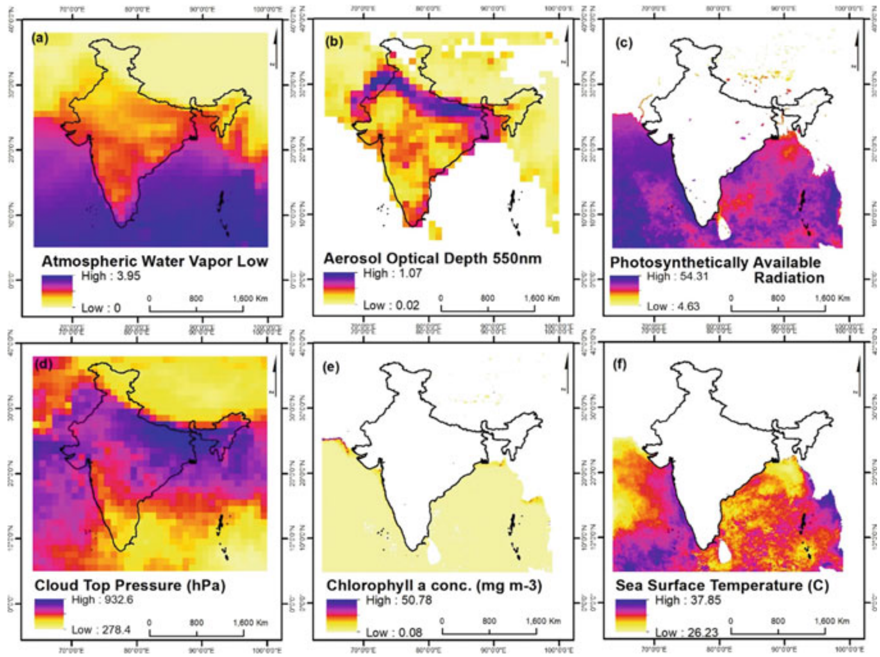

Fig. 1 Example of MODIS data products **a** atmospheric water vapor low, **b** Aerosol optical depth (550 nm), **c** photosynthetically available radiation, **d** cloud top pressure over Indian Subcontinent, **e** chlorophyll A concentration, and **f** sea surface temperature *Source* NASA EOSDIS

as well as the incorporation of traditional local knowledge in decision making (Huq et al. 2006; Satterthwaite et al. 2007). Adaptation to the negative impacts of climate change generally takes place in two ways, i.e. either anticipatory (before the impacts take place) or reactive (as a response to initial impacts) (Mitra et al. 2008). For any effective adaptation strategy, it needs to be focused mainly around two important pillars of building resilient livelihood and designing robust infrastructure that takes into account the potential impacts of climate change (World Bank 2009). India is also putting efforts to combat the effects of climate change through certain national mitigation strategies. It has targeted the coal, transport, petroleum, steel, cement and agricultural sectors by promoting energy conservation, alternative fuels, renewable energy technologies and afforestation programmes (Padma 2006). The Indian government has taken initiatives by participating in global efforts through a number of programmes. It has one of the largest renewable energy programmes in the world, with about six percent of grid capacity based on renewable source of energy. India has brought not only National Auto-fuel Policy which has mandated cleaner fuels for vehicles but also the Energy Conservation Act that aimed to improve energy efficiency (Bhandari 2006). India has also launched a National Action Plan on Climate Change (NAPCC) that identifies a number of measures that simultaneously advances the country's development and climate change related objectives of adaptation and mitigation (MoEF 2014). The solar, energy efficiency, and forestry missions of the action plan include mitigation components in the form of quantified targets while, missions on sustainable agriculture, water and sustainable Himalayas are purely adaptive in nature (Rattani 2018). These measures will moderate India's energy and emissions-intensive growth, thereby contribute towards the combating the effects of climate change (Bhandari 2006).

11 Future Research Prospects and Recommendations

- Integration of climate change science into resource management plans and adaptation actions.
- Historical impacts and future vulnerabilities at the ecosystem level is the major challenge to manage for potential future conditions, rather than to manage for past conditions.
- Agro-ecosystems differ in the ways they sustain the farmer's agility to respond to external pressures, stresses and fluctuations. Therefore, farmers' management can play an important role in adaptation.
- The complex interactions of grazing, inter-annual precipitation variability, precipitation seasonality, fire, and pests can result in rapid ecosystem transitions. These complex interactions should be studied thoroughly on long term basis to determine the impacts of climate change at local and regional scales.
- Modeling studies incorporating climate change drivers, land-use data, and ecosystem processes warrants future research.
- Reformation of current agricultural activities to maximize effective availability of products and adapt in the changing climatic conditions.
- In the present scenario of climate change and land degradation, agroforestry has real potential to contribute to food security, climate change mitigation and adaptation, while preserving and strengthening the environmental resource bases.

12 Conclusion

Climate change has been acknowledged very well as a global phenomenon that impacts societies throughout different scales that ranges from individuals to localities and entire regions. Various sectors such as coastal ecosystems, biodiversity, water, human health, energy, transportation, forests, and agricultural productivity are being subjected to the maximum exposure to climate change in India. The concepts of resilience and sustainability are well established in agriculture as well as forestry sectors and can be linked directly to the climate change arena for better adaptations and mitigations. A number of steps are also being taken by the Indian government in order to effectively respond to climate change. Despite these steps, India needs to formulate a national strategy in view of multiple vulnerabilities to adapt to climate change and to further enhance ecological sustainability of its development path.

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Local Socio-Economic Dynamics Shaping Forest Ecosystems in Central Himalayas

Shalini Dhyani and Deepak Dhyani

Abstract In past five decades (post 1960), humans have severely manipulated ecosystems of the country than ever before. Various natural and human induced factors have been direct or indirect drivers severely affecting ecosystems and biodiversity. However, impacts' of these drivers have been seldom analyzed and hence, they remain mostly unidentified. Socio-economics is a relevant indirect driver that significantly affects the ecosystem functioning, by affecting the overall ecosystem goods and services. Socio-economic evaluations are fundamental to understand the scenarios and requirement of appropriate local and regional policy interventions that are desired to fit to the location specific requirements and dynamic patterns, coupled with the intrinsic ecosystems changes. Demands of life supporting biomass and exploitation of other forest resources are closely associated to local socio-economics. The forests of Central Himalayas are biodiversity hotspots and source of many ecosystem goods and services for the entire country. These forests appear to be limitless sources of provisioning, regulating, and supporting and cultural ecosystem services. Forests in Central Himalayas have been severely exploited in last few decades for various essential and subsistence demands of locals as well as other larger demands for development in the country. Degraded forest ecosystems generate limited goods and services and are not able to support good quality of life of marginal communities. It is vital to address dependence and requirements improving socio-economics of locals that leads to sustainable utilization of forest resources. Present chapter investigates socio-economic reasons, affecting forest health in Central Himalayas. Dynamics of social and economical set up driving change in forest resource use is imperative to identify opportunities for adaptive and sustainable forest management. Present study provides perspectives based on literature reviews, primary data collected from fields

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and socio-economic surveys based on informal group discussions and focused personal interviews. Study focuses on the need of developing and supporting existing local forest governance institutions for effective conservation of forests. Paper looks into future prospects and research needs concerning the assessment and management of forest ecosystem services by addressing socio-economics by targeting long-term conservation initiatives to achieve long term and short term biodiversity conservation targets.

Keywords Central Himalayas · Forests · Ecosystem services · Social-ecological systems · Socio-economic drivers · Biodiversity loss · Policy issues

1 Introduction

Diversity of life on earth is histrionically affected by human alterations of ecosystems. Many activities imperative for human subsistence requirements is leading to biodiversity loss. Ecosystems across Asia are threatened by array of drivers, each of which increases the probability of loss of biodiversity from a variety of ecosystems (Hughes 2017). Environmental change has been a frequent and continuous phenomenon in nature but the level, rate and extent of this change has been significant in last few decades leading to complex, significant, strong and unforeseen affects on socio-ecological systems (Chapin et al. 2000, 2001). Central Himalayas have wide range of forests supporting wealth of biological diversity and endemism among plants and also animals of the country (Misra 2009). Forest ecosystems in Central Himalayas are important for well being for a larger population of the country and for millennia they have been supporting subsistence life style of local communities (Dhyani and Dhyani 2016). Although, the area is one of the biodiversity hotspots yet it is biotically threatened because of various direct and indirect drivers of biodiversity loss. Ecosystems in Himalayas are severely manipulated because of enhanced demands of natural resources for the development of the country by continuous man made interferences in natural ecosystems than ever before. Various natural or human induced factors affecting the area are many direct and indirect drivers of deforestation and biodiversity loss that have severely affected natural ecosystems of the region. Indirect drivers are important underlying causes of biodiversity loss and impaired ecosystem services. Drivers have been observed to behave differently over different spatio-temporal scales and indirect drivers being important root causes of environmental damage have seldom been acknowledged and considered for influencing important global environmental issues and policy frameworks. It has been already proven that drivers of biodiversity loss are embedded in socio-economic, socio-political, cultural, technological advancements, environmental governance, policy and political framework of the society and nations (Haberl et al. 2007). As per IPCC impacts of climate change are envisaged to significantly affect forests and forest dependent agriculture thus, affecting food security. Climate led variabilities and vulnerabilities are already threatening the fragile terrains and ecosystems as well as the livelihoods of people dependent on them (Dhyani and Dhyani 2016). Increased frequency of extreme climate events such as frequent floods, incidences of cloudbursts coupled with heavy rainfall have enhanced soil erosion and slope instability in the region at large. Deforestation and reduced natural resources in vicinity of human habitations are resulting into conflicts related to resource sharing, and reduced opportunities for good quality of life has led to emigration (IPCC 2014). Increasingly, the conservation community across the world is recognizing the importance of scaling up the efforts from local to regional and later to national level to understand the actual reasons behind biodiversity loss leading to reduced ecosystem services at various levels. Socio-economic reasons of biodiversity loss are significant but actual frequencies of biodiversity loss due to direct drivers (habitat destruction, climate change, nutrient and pollution load etc.) are so strong that it is a challenge to identify and seek solutions for socio-economic drivers. It is pertinent to understand how local, regional or national socio-economic conditions can influence environmental degradation. Such approaches require deeper understanding and knowledge of different socio-economic and socio-political scenarios as important drivers of biodiversity loss present in local, regional, national and international levels. Impact of improving the socio-economic conditions by addressing livelihood options has the potential to halt, reduce and reverse degradation of environment in resource rich areas. Unfortunately, policy makers, natural resource managers, researchers and scientific organizations working in the rugged, undulating and fragile terrains of Himalayas have little information about how targeting livelihood of locals and improving socio-economic conditions can help protecting and conserving natural resources. By involving local communities in conservation may not only help to respond to these emerging local, socio-economical, institutional and other major global drivers of change but also help to harness long term conservation benefits (Place and Keijiro 2000). Present study has tried to understand the impacts of local socio-economic conditions leading to biodiversity loss from Central Himalayas. Author bring the perspective of local socio-economic drivers as vital reasons that are shaping the future forest development in the region along with global drivers of change (climate change, invasion of species, ever increasing demand of MAPs, increased power demands of the country etc.) However, when the local and indirect drivers are intersecting with the global drivers of change, they are introducing new challenges for conservation communities that require innovative responses. These responses are to be area specific or common for the areas that face similar drivers facing similar scenarios. Study looks into aspects of socio-economic drivers under following objectives:

i. How socio-economic drivers have affected biodiversity of the region and where are the key examples existing
ii. What are effective solutions available in terms of policies and strategies to respond to these challenges; and
iii. Why community collaborative efforts are important by acknowledging communities as important stakeholders of biodiversity conservation in Central Himalayas.

2 Study Area

Uttarakhand state of India falls under the geographical boundaries of Central Himalayas and has two administrative provinces viz. Garhwal and Kumaon part. Primary information to support the study was carried out in Garhwal part of Central Himalayas. Important sites and village settlements surveyed for the study were situated in upper Kedarnath valley (1600–2500 m amsl) in district Rudraprayag; Kanchula *Kharak* (1800–2000 m amsl) in Kedarnath Wildlife Sanctuary, Tolma and Suraithota village (2000–2800 m amsl) in Niti valley, Langasu village cluster (900 m amsl), Ghes and Van village (2400 m amsl) in Pinder valley of district Chamoli, Doodhatoli and Binsar (2000–2400 m amsl) in Pauri Garhwal; Deoprayag (600 m amsl) in district Tehri and Harsil and Gangotri (2400–2900 m amsl) in district Uttarakashi. Geographical locations of the study sites were situated with in latitude 29° 30′ to 31° 30′N and longitude 77° 30′ to 80° 15′E of the state. Climate of the study area is varied according to the altitude but in general warm dry months of summers are followed by warm wet months of monsoon and later in the year-end cool dry months. The climatic condition of the study sites are largely altitude dependent. Mean annual rainfall of the study area varies from 1300 to 25,000 mm while mean yearly temperature ranges from 23 °C at 300 m amsl (meters above mean sea level) and 13 °C and less above 2000 m amsl. Snowfall in the region is prominent climatic feature above 1800 m amsl altitudes and many of the study sites experience snowfall. Study area is endowed with diverse vegetation types, ranging from tropical moist deciduous to temperate and sub-alpine forests, grasslands, alpine scrub and meadows (Champion and Seth 1968). All the sites are home to lush green forests and are rich in terms of species diversity distributed across altitudinal gradients. Varied topography, climatic variability, migration routes from adjacent phyto-geographical zones are responsible factors for this richness in diversity with important timber species occupying the higher canopy, fuelwood, fodder and minor forest products in the middle and lower layer of canopy, with the ground flora rich in economically important species including medicinal herbs. Total recorded forest area of the state is 34,651 km^2, that is 64.79% of its total state geographical area. Reserve forest constitutes 71.01%, Protected areas 28.52% whereas; a large part of forest is also under *Van Panchayats*/Community Forests in the state. Per Capita Forest Area (Hectare) is 0.376 ha (FSI 2015; Uttarakhand Forest Statistics 2015). As per 2011 census the total population of the state is 10.09 million of which rural population is 69.77% and scheduled tribe population accounting to 0.29%. There are 16,000 villages in the state with many close to forests, dependent on forests following a natural resource based economy (Misra 2009). Population density in the study area is on an average of 189 persons/km^2. The livestock population of the state is 5.14 million as per 18th livestock census. Landholdings are meager and 49% of land holdings are >0.5 ha, 21.51% ranging 0.5–1.0 ha. Around 70% holdings are marginal with an average size of around 0.37 ha. Small land holding in undulating and fragile terrain makes agriculture insignificant option for full-time livelihood. In last few decades change in environmental conditions have also led to change in cropping patterns and crops from traditional to water intensive cash cropping.

3 Methodology

To understand the underlying factors of biodiversity loss analytical approach for root cause analysis was used as primary step. Study attempted to understand the key factors that interact with socio-economic drivers in a more complex manner. Demographic changes, poverty leading to inequalities in the societal set up, out-migration, market availability, political set up and development leading to social change to reflect on important socio-economic drivers were assessed through review of available literature. Case studies were considered as an important analytical and conceptual modeling tool to draw inferences for proposed objectives. The purpose of including case studies as relevant examples was to highlight the reasons behind rampant loss of natural resources in order to seek solutions to safe guard site-specific forest ecosystems from loss of biodiversity.

3.1 Review of Historical Records

Available forest and land use policies and annual reports from Forest Survey of India (FSI) (2003–2015) were reviewed to understand the historical and recent changes in forest cover and emerging threats to forests in the study area (FSI 2007, 2013). Secondary information on forest resources, forest produce extraction, management rights of locals on forests along with rural development projects and activities were referred to understand local involvement in forest conservation and management. Records related to historical information about study sites was taken from forest and block level government offices. Census reports of 2001 and 2011 were referred to understand demographic changes, migration patterns, settlements and local communities (Census 2001, 2011). Focussed group discussions followed with key personal interviews were important part of the study to cross check and verify information on resource rights of locals on near by forests.

3.2 Observations and Data Collection

Keeping the background of the study in mind community dependence on forests, extraction of biomass for various purposes (fuel wood, fodder, leaf litter, NTFPs etc.), anthropogenic interferences leading to adverse consequences destabilizing ecosystem goods and services was reviewed from previously published research papers of authors (Misra et al. 2008; Misra 2009; Dhyani et al. 2011, 2013; Dhyani and Dhyani 2016). Dependence of communities on nearby villages was verified by following resource removal patterns (reflecting monthly, seasonal and annual dependence) actual field surveys, personal observations, informal group discussions and focused personal interviews.

4 Results and Discussion

4.1 Forest Types in Uttarakhand Part of Central Himalayas

The major forest types of the study areas include subtropical forests (Deoprayag), moist and dry temperate forests (study areas in Uttarkashi, Chamoli and Rudraprayag), alpine areas (Chamoli) and Pine forests (Pauri Garhwal). These broad categories according to Forest Survey of India following Champion and Seth 1968 are further classified into different sub categories. These broad categories are summarized in Table 1 while; broad legal status categories are shown in Table 2.

The central and state forest department along with forest managers and development agencies in the region face the dilemma of balancing conservation and forest exploitation in the state. At present exploitation efforts far exceed conservation efforts that are resulting in loss of forest cover and threatening biodiversity due to loss and fragmentation of habitats. The loss of forests cover between 2003 and 2015 has been almost 7772 km^2 (FSI 2003, 2015) (Fig. 1) and the pace of forest loss has been accelerated 2009 onwards (Fig. 2) likely because of developmental projects planned and executed especially Hydro Power Projects (HPP) in higher reaches of the state. From the overall changes in forest cover it is evident that the deforestation rates are significant in all dense forest, moderately dense and open forests (Fig. 1). Though, altitude wise change in forest cover is not significant in 2009, 2013 and 2015 irrespective of forest category (Fig. 3). The spatial distribution of deforestation and degradation was also observed to be uneven throughout the region. Many rich forests of the region are under Reserve and Protected category i.e. 71.10 and 28.52% respectively (FSI 2009) and, a small part of forests is with community under community forests or *Van Panchayats* category as well as sacred groves (0.3%). There is unavailability of data that provides details of loss in forest cover under different legal categories of forests. Deforestation is clearly visible and significant in all the altitudes of the study area wherever human habitations are present irrespective of the legal status of forests in vicinity of these villages. Deforestation is evident at all altitudes, in all legal categories be it protected or reserved. Illegal encroachment for extensive harvesting of MAPs (Medicinal and Aromatic plants), wild edibles provide significant but invisible contributions to the loss. Poor socio-economic conditions, undulating terrains, remoteness adds to misery of locals that increases dependence on forests for food, livelihood and other daily subsistence demands.

Table 1 Major forest types and their area coverage (in km^2) in Central Himalayas

S. No.	Forest type group	Very dense forest	Moderately dense forest	Open forest	Scrub	Total
1	Group-3 Tropical Moist Deciduous	1104.44	2806.19	715.50	8.18	4634.31
2	Group-5 Tropical Dry Deciduous	81.00	851.15	568.51	78.00	1578.66
3	Group-9 Subtropical Pine Forest	768.67	4432.01	1721.46	189.11	7111.25
4	Group-12 Himalayan Moist Temperate	1612.45	5014.49	2434.98	28.12	9090.04
5	Group-13 Tropical Moist Deciduous	199.96	171.97	75.65	1.18	448.76
6	Group-3 Tropical Moist Deciduous	185.98	709.92	131.85	9.75	1037.5
7	Group-3 Tropical Moist Deciduous	21.87	103.53	39.81	5.59	170.8
8	Group-3 Tropical Moist Deciduous	0.98	26.87	11.58	0.07	39.5
9	Plantation/TOF	26.65	279.87	344.66	0.00	651.18
Total		4002.00	14396.00	6044.00	320.00	24762.00

Source FSI (2015)

Table 2 Total occupied area under different Legal Status of Forested Land in the study area

Legal status	Name	District	Area (km^2)	Total area (km^2)
Biosphere Reserve (01)	Nanda Devi Biosphere Reserve	Chamoli, Pithoragarh and Bageshwar	5860	5860 (Includes area of Valley of Flowers NP and Nanda Devi NP)
National Park (06)	Corbett NP, Gangotri NP, Govind NP, Nanda Devi NP, Rajaji NP Valley of Flowers NP	Nainital & Pauri Garhwal; Uttarkashi; Uttarkashi; Chamoli; Dehradun, Pauri Garhwal & Haridwar; and Chamoli respectively	520.82 2390.02 472.08 624.60 820.00 87.50	4915.02
Wildlife Sanctuary (07)	Askot WLS Binsar WLS Govind Pashu Vihar WLS Kedarnath WLS Mussoorie WLS Nandhaur WLS Sonanadi WLS	Almora; Uttarkashi; Chamoli & Rudraprayag; Dehradun; Nainital & Champawat and Pauri Garhwal respectively	600.00 47.07 485.89 975.20 10.82 269.96 301.18	2690.18
Conservation Reserves (04)	Asan Wetland Jhilmi Jheel Pawalgarh Naina Devi Himalayan Bird	Dehradun Haridwar Nanital Nanital	4.444 37.84 58.25 111.9	212.434
Sacred Groves (>126)	–	Almora, Chamoli, Pauri, Pithoragarh, Bageshwar, Tehri, Rudraprayag	–	–
Community Forests/Van Panchayats (12,064)	–	Chamoli, Pauri, Tehri, Uttarkashi, Dehradun, Rudraprayag, Nainital, Almora, Pithoragarh, Champawat and Bageshwar	–	(7350.85) 5232.89
Reserve Forests				26,547

Source GBPNIHESD ENVIS (2015), WII ENVIS (2016)

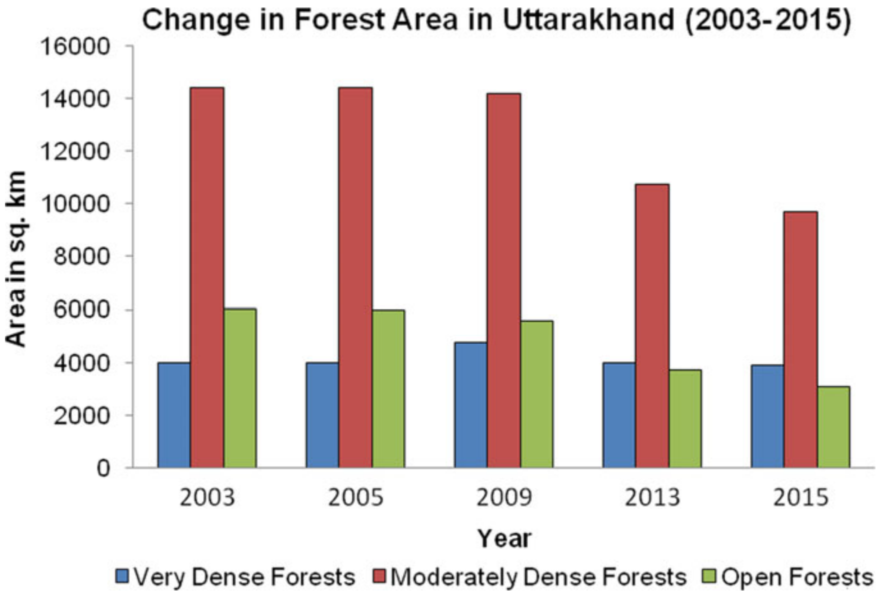

Fig. 1 Temporal and spatial change in forest cover in Central Himalayas (2003–2015)

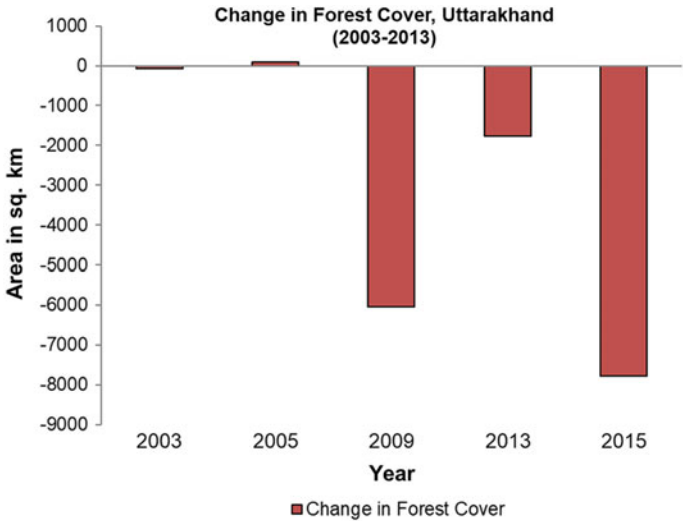

Fig. 2 Drastic decline in forest cover in Central Himalayas (2003–2015)

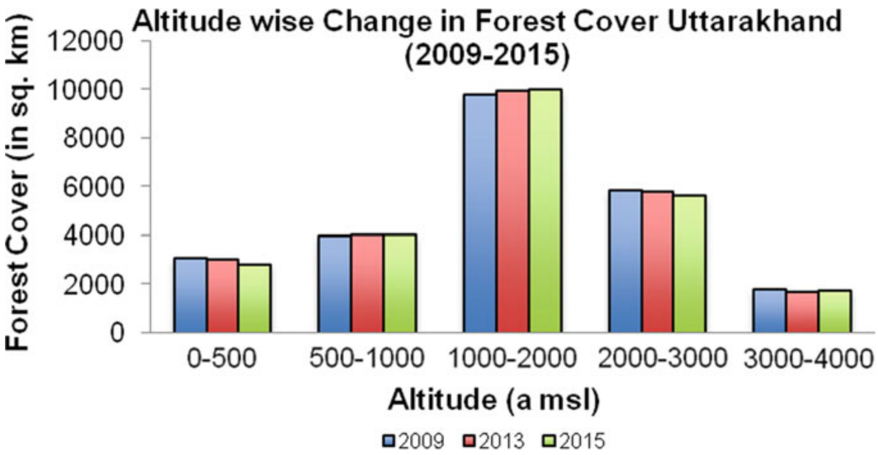

Fig. 3 Temporal and spatial change in forest cover at altitudinal gradient (2009–2015)

4.2 Threats and Challenges to Forest Ecosystems and Biodiversity in Central Himalayas

Indian government has established a comprehensive network of reserve or revenue forests and Protected areas to ensure a supply of economic, social, and environmental benefits from forests. Forests of the study area provide significant support to locals in terms of food, water, fuelwood, fodder for their animal, leaf litter also a lot of MAPs, wild edibles and other NTFPs etc. The region's forest resources contribute significantly to the local people of the area, as well as down stream people for supporting and uplifting the economy of the country that is seldom acknowledged. High altitude districts and study sites are still under developed and forests still contribute directly to livelihood of more than 50% population that lives below poverty line (BPL) (623,392 households). Forests indirectly support and nourish agriculture and supply food and nutrition to rural communities in the region (Census 2011). There are several economic, political and social dynamics that shapes the use and is significantly contributing to transform forest landscapes of the area. Deforestation and biodiversity loss at local level is driven by expansion of agriculture in forests, hydro power projects, increasing demand and illegal extraction of MAPs, wild edibles and other NTFPs, fodder, fuelwood, timber, change in cropping patterns from indigenous and traditional to cash crops etc. (Table 3).

The major threats to these ecosystems include the following.

Table 3 Forest ecosystem types and the dynamics shaping the use and transformation of forest landscapes in Central Himalayas

Altitude (a msl)	Forest type	Tenure/Institutional Arrangement	Dynamics leading to changes in forest landscapes	Weakness undermining institutional ability to address emerging challenges	Principal opportunities to address emerging socio-economic challenges
500–1000	Subtropical Pine Forest	Mostly Reserve and few pockets of community forests/*Van Panchayats*	Biomass harvested for fuelwood, fodder, leaf litter, NTFPs, encroachment for agriculture, grazing, forest fires	Increasing population pressure though emigration is also happening, increasing livestock population, lack of alternative livelihood, fodder demands, weak forest governance, less community involvements and rights, corruption	

(continued)

Table 3 (continued)

Altitude (a msl)	Forest type	Tenure/Institutional Arrangement	Dynamics leading to changes in forest landscapes	Weakness undermining institutional ability to address emerging challenges	Principal opportunities to address emerging socio-economic challenges
1500–2500	Himalayan Moist Temperate (Mixed Broad leaved Oak forests)	Mostly Reserve and few pockets of community forests/*Van Panchayats* and Protected forests	Biomass harvested for fuelwood, fodder, leaf litter, NTFPs, charcoal preparation in some pockets, encroachment for agriculture, grazing, forest fires	Lack of alternative for energy, low temperature, poverty, communal grazing, stall feeding, temporary transhumants, Increasing population pressure though emigration is also happening, increasing livestock population, lack of alternative livelihood, fodder demands, weak forest governance, less community involvements and rights, corruption, shifting of cropping patterns from indigenous to cash cropping	High eco tourism potential, Carbon trading potential, existence of forest rights act, 2008; close forest status assessment; Establishing Ecodevelopment committee inlines of Joint forest Management for developing community partnerships; promotion of LPG as energy source and also solar with some subsidy

(continued)

Table 3 (continued)

Altitude (a msl)	Forest type	Tenure/Institutional Arrangement	Dynamics leading to changes in forest landscapes	Weakness undermining institutional ability to address emerging challenges	Principal opportunities to address emerging socio-economic challenges
2000–3000	Himalayan Dry Temperate (Conifer forests)	Mostly Reserve and few pockets of community forests/*Van Panchayats* and Protected forests	Biomass harvested for fuelwood, fodder, leaf litter, NTFPs, charcoal preparation in some pockets, encroachment for agriculture, grazing, forest fires	Lack of alternative for energy, low temperature, poverty, communal grazing, stall feeding, temporary transhumants, Increasing population pressure though emigration is also happening, increasing livestock population, lack of alternative livelihood, fodder demands, weak forest governance, less community involvements and rights, corruption, shifting of cropping patterns from indigenous to cash cropping	High eco tourism potential, Carbon trading potential, existence of forest rights act, 2008; close forest status assessment; Establishing Ecodevelopment committee inlines of Joint forest Management for developing community partnerships; promotion of LPG as energy source and also solar with some subsidy

(continued)

Table 3 (continued)

Altitude (a msl)	Forest type	Tenure/Institutional Arrangement	Dynamics leading to changes in forest landscapes	Weakness undermining institutional ability to address emerging challenges	Principal opportunities to address emerging socio-economic challenges
3000–3500	Timberline	Mostly Reserve and Protected forests	Grazing, NTFPs and MAPs collection, poaching	Lack of alternative livelihood, poverty, loss of rights, corruption, illegal trade of MAPs, enforcement issues, weak forest governance, geographical sensitivity, remoteness	Carbon trading potential, ban on transhumants and grazing, close forest status assessment; Government creating market for MAPs sale and also rotational sustainable removal of some medicinal plants, enforcement
3500–4000	Alpine Areas	Mostly Reserve and Protected forests	Grazing, NTFPs and MAPs collection, poaching	Lack of alternative livelihood, poverty, loss of rights, corruption, Illegal trade of MAPs enforcement issues, weak forest governance, geographical sensitivity, remoteness	Ban on transhumants and grazing, close forest status assessment; Government creating market for MAPs sale and also rotational sustainable removal of some medicinal plants, enforcement

4.3 Increasing Population

According 2011 Census of India, state population has reached approximately 1.01 crore with an increase of 19.17% from the past decade from 8,489,349 and has increased manifold in last seven years till 2017. High population pressure zones reside in valley towns and districts of the state that are centres of education, livelihood and medical health care facilities (Census 2001, 2011). Emigration rates were 0.4 per 100 persons for the region in 1991–2001 (Census 2001). These rates have increased in last more than a decade because of lack of livelihood and other opportunities. Women are mostly involved with resource collection from forests to support daily subsistence requirements. Locals in villages with no community forests encroach other forest legal categories for various resources demands. Nepal border is close to state boundaries and ease of livelihood brings a lot of poor Nepalese in the state. They work as daily wages, porters and also as servants in local villages and towns and are involved in illegal harvesting of MAPs along with poaching of threatened fauna. Increasing Nepalese migrants in the state has also resulted in illegal resource exploitation and biodiversity loss. Changing rainfall and snowfall patterns, increased frequency of extreme weather events along with unsustainable forest extraction was reported by local informants as key to loss of biodiversity. This was common information gathered from informants in all study sites. A large chunk of vegetation riparian fringes on the banks of rivers and tributaries are either submerged or will be submerged to facilitate functioning of many hydropower projects in the state. Some common observations are emergence and accentuation of cumulative environmental changes, leading to unsustainability of previously sustainable subsistence systems (Misra et al. 2009; Jodha 2001).

4.4 Biomass Dependency of Local Communities on Forests in Central Himalaya

Resource dependency of locals has always been demand-driven rather than supply-driven. Due to insufficient yield from agriculture and less availability of fuelwood and fodder from agro-forests traditional arrangements in the study areas are changing. Due to lack of economic incentives, resource rights and ownership for conservation of natural forest ecosystems, locals are less motivated to protect the forests. Although, study area villages spread in different valleys of Central Himalayas have their large area under forests still these forests are under stocked and have low tree density. As a result of degradation and deforestation that is now prominent in many areas are facing denudation of trees, reduced stock density coupled with loss of surface soil, leaching of nutrients and decreased crop production from forest dependent marginalized agriculture. Forests in Central Himalayas as observed during field survey are under continuous pressure due to unregulated and illegal encroachment of fragile forests, alpines and pastures for NTFPs and MAPs, frequent man-made forest fires leading to encroachment of invasive species due to degraded habitats. The average family size in all the sites of the study area was observed to be 6–8 individuals/household. Local communities in the study area utilize a large number of plants from forests in their day-to-day life. Plant species used by locals besides timber yielding are also oil yielding, fodder yielding, species supporting livestock rearing, agriculture, spices and many other wild edible species.

During the survey, data on biomass demands and extraction by locals around the year was collected to understand quantities of forest resources in specific seasons (Fig. 4).

Informants reported variations in biomass collection from forests, and it was observed to be dependent on socio-economic status of local inhabitants and on the availability of resources in their village vicinity. Informants reported on an average 6–10 kg/day of fuelwood requirement and collection by locals during summers (May–July) and 15–20 kg/day during winters (November–March) irrespective of collection (Table 4). Fuelwood requirement and utilization was reported to be higher because of less availability and high cost of alternative energy source available such as biogas or L.P.G. cooking gas in the study areas. Temperature maintenance was an important reason for high fuelwood demand during winter months. Household size was an important criteria for understanding fuel wood demand and extraction rates per household. Fodder and leaf litter extraction was observed to be dependent on livestock holding/household. Fodder demand and supply in all the study

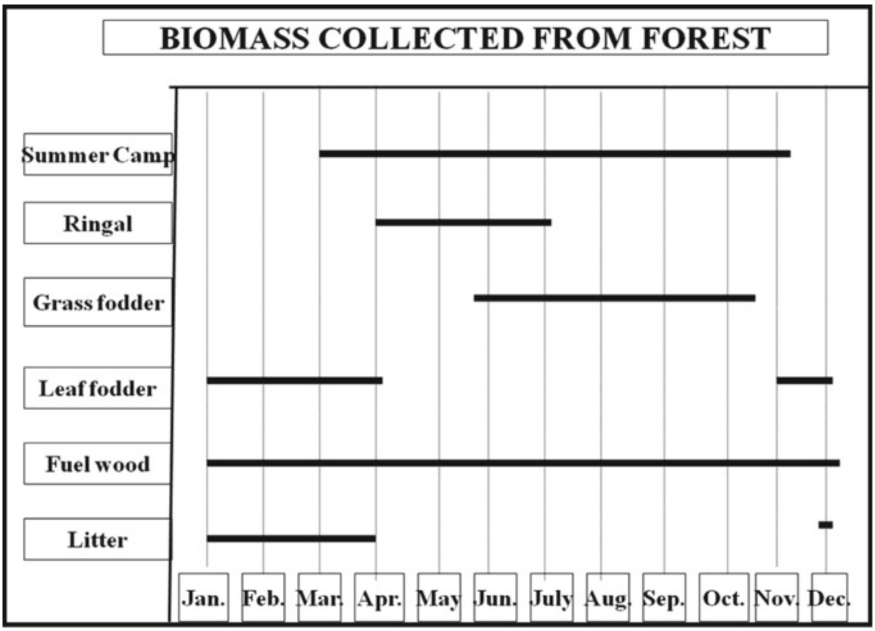

Fig. 4 The results of a Seasonal Calendar of biomass removal from nearby forest areas derived from people's consultation (Misra 2009)

Table 4 Indigenous resource use pattern in the villages of Central Himalayas from mixed broad-leaved moist temperate and dry temperate forests (700–3000 m msl)

Resource type	Extraction process	Frequency	Consumption calendar	Average
Fuel wood	Felling Lopping Collecting	Once in 2–3 days	Entire year	35.00 kg/2–3 day
Fodder	Lopping, Chopping	Twice a day	February-May and August–September	86.8 ± 10.5 to 157.5 ± 17.5 kg/day
NTFP and Wild edibles	Lopping, Chopping, Uprooting	2–3 Times a week	March–June	1.5 kg/Household/week
Leaf Litter	Collecting	Twice a day	November–April	45 kg/Household/day

* *Consumption is averaged for all households of all sites* (Misra 2009; Dhyani and Dhyani 2016)

sites was also reported to be uneven throughout the year and scarcity of fodder is also due to lack of smart planning to utilize crop byproducts and other resources. Demand and supply of fodder during winter/lean period was reported to be a serious issue that results in women drudgery and resource extraction conflicts in all the villages (Dhyani et al. 2011). Dry leaf litter during winter months is collected from forest floor as per preference of locals (fast decomposing leaves) and subsequently a large amount of leaf litter is collected for cattle bedding later used in making farm yard manure (FYM) to support nutritional requirements of crops and agriculture fields. Removal of leaf litter was observed to be accidentally removing of seeds from forest floor during field surveys. Practice likely hampers regeneration of many important tree species with small seeds and insufficient soil seed banks. NTFP collection is considered to be a regular activity in study villages and different sites have different NTFPs. No resource rights have been associated with NTFP collection unless it is in bulk for commercial purposes (Hall and Bawa 1993). Collection of resources from forests was reported by local informants of Chamoli and Rudraprayag districts to be an intense and exhaustive practice because of poor socioeconomic conditions of locals, meagre, unreliable and insufficient yield from traditional agriculture practices and pressure to use natural forests as easiest alternative livelihood options (Misra et al. 2009).

Local communities practice animal husbandry as an important source of livelihood along with agriculture. Each family was found to be maintaining 3–5 cattle that included bovines (a pair of bullocks to support agriculture, a cow and/or a buffalo to support dairy requirements and a horse/mule for alternative livelihood as pack animals). All cattle are stall-fed and few families also leave their cattle with few temporary transhumant for free grazing in surrounding, forests and *kharaks* (Misra 2009; Dhyani et al. 2011). Summer camps (Fig. 4) represent extraction of resources by temporary or permanent transhumants who camp in high altitude alpines and pastures with livestock for grazing. They exert more pressure on forests/household than a normal household has on forests of lower altitudes. Every year for Kedarnath yatra that majorly lasts for 02 months (May to June) more than 5000 pack animals are brought from far and nearby locations of the state and also from outside the state. These animals exert extra additional pressure on alpines and pastures for their fodder demands by free grazing as well as stall feeding (Misra et al. 2009). Till 2005–2006 permanent summer transhumants of *Gujjar* community were allowed to graze their buffaloes in pastures and alpine areas of Central Himalayas later a ban was imposed after it was observed their animals (50–100/household) exert pressure on alpine areas beyond the carrying capacity of these pastures (Misra 2009). Winter transhumant population of Indo-Mongoloid *Bhotiya* tribes in Uttarakashi, Chamoli and Pithoragarh were also banned to graze their sheep in pastures after these pastures and alpine areas were notified as Protected Forests after Wildlife Protection Act, 1972. Slowly indigenous *Bhotiya* tribal community is leaving the traditional practice of livestock rearing but has shifted to collection of MAPs from alpines and subalpines. Locals were historically trained and skilled to survive in high altitude areas by practicing certain livelihood practices that were more traditional and natural resource dependent viz. agriculture in lower altitudes (500–1000), agriculture and livestock rearing in middle altitudes (1000–2000) and livestock rearing and MAP collection in higher altitudes (>2000 m amsl). It is clear that not acknowledging rights of locals and indigenous communities has likely led to illegal harvesting from forests by locals.

Dwarf or *ringal* bamboo (out of five species only two *Drepanostachyum falcatum* and *Thamnocalamus pathiflorus*) species are observed to be removed at an average number of 500 culms/household/biannualy as strong crop support to local *Cucurbit* and Kidney bean plants in Upper Kedarnath valley. Bamboo culms are no cost resource supporting daily subsistence and also alternative livelihood (by making and selling baskets etc.) supporting their socio-economic conditions. Most flexible and strong bamboo culms were observed to grow in higher reaches of timberline forests hence, their large scale removal may affect forest health of these fragile ecosystems in higher reaches. *Ringal* bamboo species are under threat because of unregulated removal from high altitude forests and hence, ban has been imposed on collection from valley forests of Kedarnath, Chopta etc. by forest department since 2005. Few such NTFP/MAP removal examples that are leading to major biodiversity loss and habitat degradation because of poverty, lack of understanding among locals how these extractions are ruthlessly damaging fragile and sensitive forests are presented below.

4.4.1 Prevalent Socio-Economic Driver Behind Extraction of *Cordyceps Sinensis*

Cordyceps sinensis commercially referred as Himalayan Viagra is a fungi and parasite that grows on larval stage of a lepidopteran species in alpine pastures of Central Himalayas. Species has been in huge demand internationally because of its proven aphrodisiac properties in Chinese medicine and for locals it has been a gold rush. *Cordyceps* grows above 4000 m amsl in alpine pastures near snow line in all the study sites and is collected during snow melt period post winter months (from April to mid June). China is important market for *Coryceps* and the species is also used during religious ceremonies in Indonesia and Tibet. Collection and trade of *Cordyceps* is largely illegal and unregulated in Central Himalayas. The important driver of ruthless extraction of species is poor socio-economic status of locals, availability of the species in nearby alpine area and collection area being close to China borders. The species has high rates in local hidden markets (from 55–65,000 in 2004 to 10–1,500,000 per kg in 2017) and has the potential to fetch more than 4,000,000/kg in international market of China. Rates for the species have multiplied every passing year because of it's unending demand. This species has unorganized trade and significant impact on rural economy in remote and undulating valleys of Central Himalayas. Empty villages during summer months and degraded alpines because of extensive human encroachment are clear reflections of socio-economics being a mega driver to huge biodiversity loss. College going students return to village for collection of species spending many days in cold and harsh conditions. Nepali immigrants from bordering Nepal are also involved in illegal trade coupled with poaching activities.

Rapid constructions of *pukka* houses and early marriages in high altitude traditional and *Bhotiya* tribal communities are changes that are been observed due to influx of money by extraction of *Cordyceps* in Niti valley, Doodhatoli and Binsar areas. After ban been imposed on grazing, collection of MAPs from high altitude areas in early 1980s locals and indigenous people went out of livelihood. For local families under BPL (Below Poverty Line) this species has emerged as a significant alternative livelihood option though, long periods to survive under extreme cold conditions have exerted huge pressure on timberline vegetation. Threatened species of *Betula utilis* in timberline is largely used as an important source of firewood during the period of collection. Continuous presence of large number of people in fragile landscapes of alpine and subalpine areas during regeneration period of many threatened MAPs poses threat to their survival. *Cordyceps* has not found mention in Ayurvedic or Indian system of medicine and has no market in India hence, ongoing extraction of species for Chinese medicine has led to biodiversity loss, damage to high altitude fragile ecosystems (Sharma 2004; Garbyal et al. 2004).

4.4.2 Shadowy Trade of Medicinal and Aromatic Plants

Central Himalaya is a significant habitat to commercially important and many threatened medicinal and aromatic plants (MAPs). About 2500 plant species are utilized in different Indian system of medicines while, more than 1750 herbal species are native to Indian Himalayan region. Central Himalayas has a share of more than 1000 species, which are in use. About 121 plant species of the region are in IUCN Red data book while, Red data book published by Botanical Survey of India has identified about 214 species of endangered flowering plants out of which 29 species have been listed under rare category and some of them are at the verge of extinction (IUCN 2001; Ved et al. 2003). The numbers of these plants have increased over years due to unregulated harvesting of resources. Most of the MAPs in Central Himalayas are found in higher reaches of alpine, subalpine, timberline, moist and dry temperate forests. MAP extraction from these reaches is restricted and illegal unless permitted still a lot of families in Chamoli district, Uttarkashi, Pauri and Rudraprayag district are dependent on them as alternative sources of livelihood by collecting and selling them to middle men or locally.

4.4.3 Extraction of Lichens as an Alternative Livelhood to Locals

Lichens are ecologically important as they provide food, shelter and nesting materials for a variety of wild animals (Pandeya and Yadava 2016; Kumar 2009; Misra 2008; Kumar and Upreti 2008). Extraction of lichens from September to March month of every year is an important alternative livelihood option for poverty laden local communities of Ghesh and Van village in Pinder valley of Chamoli district. Lichens have huge commercial demand as key ingredient in different dye, perfumery and traditional medicine industries. Lichens are also in high demand in international markets of South East Asian countries. Major share of tradable lichen species come from the mixed broad-leaved moist temperate forests. During our field surveys it was observed that lichens collected from Central Himalayan forests gets maximum profit in local *mandis*. Parmeliaceae and Physciaceae families are most commercially preferred and exploited species of lichens from the study area. Lichen is an important NTFP collected by locals as well as Nepali immigrants and more than 800 metric tons of lichens are reported to be collected from the study area. 50–80 tons of lichens is reported to be exported to neighbouring as well as European countries (Shah 1997). Almost a decade back lichen was fetching Rs. 30/kg (Upreti et al. 2005) to locals in the local markets and in a decade the rates have increased manifold and now locals can earn 100–300 Rs./kg from lichen after grading them. Though, the rates still less to support good quality of life in remote hills yet collector can earn reasonable income from this alternative livelihood having some knowledge of the fall and seasonal pattern. Complete as well partial lopping of branches of host trees results in getting better amounts of lichen. Oak is dominant tree of moist temperate forests in Kedarnath valley in Rudraprayag, Chamoli and Pauri and also an excellent host for luxuriant growth of lichens and a huge amount of lichen comes from Oak forests. Lichen overharvesting has eventually become a common practice and collectors prefer to lop branches of trees and fell old trees for lichen collection. Felling and complete lopping of economically and ecologically important tree species in large proportions are reducing their chance to dominate the canopy formation and hence, having a significant impact on regeneration of dominant and associated species. Practice of unsustainable harvesting has influenced species composition and likely affect structure and functioning of entire forest ecosystem. Depletion of lichen from forests is a matter of concern from conservation standpoint.

4.4.4 Overharvesting of *Morchella* for Economic Benefits

Morchella esculenta and other wildly growing morals (*Morchella*) are important dietic support to locals dwelling in remote and undulating valleys of Central Himalayas where market supplies are still not organized. But over the years the increasing demand of *Morchella* in urban restuarents for serving exotic dishes and availability of resources in forests has influenced many families. Local communities dwelling in high altitude valleys (Dharma, Mana, Khiron, Gangotri, Yamunotri, Niti and Mana valley) collect and sell them as alternative livelihood. Earlier every second household of the valley used to collect approximately 2–3 kg of fresh morals along with other wild leafy edibles from forests while going for livestock grazing etc. These collections were shared among other village local households and bartered for necessary requirements. But in last few years middle men have been approaching the locals for supply of morals to feed urban mobs. The amount as reported by locals ranged from 2000–2500 per kg in dry weight a decade back but like the rates of any other MAPs the prices are reported to be increasing every passing year. In 2008 the rates were 4500/kg and in 2017 the rates were exceptionally high and morals were sold at 12,000/kg as per data gathered from local informants and middle men in

Tolma and Suraithota village of Niti valley. Though, collection of morals has always been a second priority for locals but increasing rates and easy availability in nearby markets has led to regular forays and collection of MAPs from forests. According to Singh and Rawat (2000) the total income earned in a season provides 20–30% of the annual cash income in 140 villages while Prasad et al. (2002) have reported an annual income of US$ 150 for 1600 households in 40 villages. The benefits to rural livelihoods are significant and widespread and large number of rural folks thus earn a significant amount of economic benefits out of it (Negi 2006; Singh and Rawat 2000; Prasad et al. 2002).

4.4.5 Forest Fires for Quality Fodder Demands

Fires in the state occur during the pre-monsoon summer period of moisture stress and are mostly man made. Forest fires are prominent from March to May to clear forest understory by locals so that good under storey shrubs and herbs, grasses emerge during-and post-monsoon to provide green feedstock for cattle in the villages. Besides the direct losses of biodiversity, the other damage due to these fires is loss of soil fertility, soil erosion, drying up of water resources etc. In 2016 huge damage of forest biodiversity happened due to man-made forest fires. Forest fires are an integral part of the *Chir*-Pine (*Pinus roxburghii*)-*Banj* oak (*Quercus leucotrichophora*) forest zone (generally, between 800 and 2000 m altitude) (Fig. 5), promotes regional domination of *Chir*-Pine at the expense of broadleaf oak forests (Singh et al. 2016). Slowly but continuously *Banj* Oak forests are encroached by Pine trees and other exotics species like *Parthenium, Lantana* and *Eupatorium* in Central Himalaya (500–1800 m msl) resulting in substantial biodiversity loss. Forest fires in 2014 were spread in

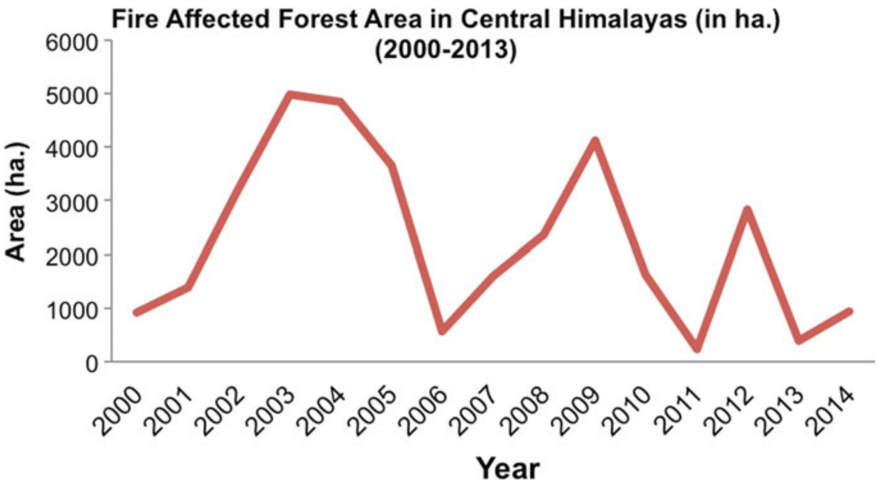

Fig. 5 Loss of forests due to forest fires in Uttarakhand, Central Himalayas (2000–2014)

930.325 ha of the forest area and resulted in monetary loss of Rs. 2357707.00 as estimated by State Forest Department (Fig. 5) (Uttarakhand State Forest Department 2016). Though, the loss is manifold as Forest department only considered timber cost for estimating the loss incurred.

Examples discussed reflect poor economic condition to be an important precursor in involvement of locals in many unsustinable and overharvesting of resources without any idea of the consequences of their activities. Collaborative resource management in some villages has been successful by creation of Eco-development Committees and also in well-managed communal forests/*Van Panchayats* of the region. The weakness that undermine institutional ability to address the challenges of increasing demand for natural resources and biomass from forests of Central Himalayas include:

- Less availability of alternative and cheap energy resources. Remoteness of villages and undulating terrains adds to inaccessibility to these energy resources
- Continous fodder requirements for livestock rearing practices that include both stall feeding and grazing
- Reserve and Protected Forests that exclude traditional and indigenous communities for sustainably collecting resources for supporting their subsistence requirements
- Limited incentives to sustainable management of forests by rotational harvesting as under *Van Panchayats*
- Low appreciation and understanding about the importance and value of forest biodiversity for future by the surrounding communities
- No sense of ownership because of stringent forest policies that are less flexible for locals and more flexible for industrial exploitation
- Not acknowledging the rights of locals and indigenous communities on forest lands under Forest Rights Act, 2008
- Better profitability of alternative land uses such as tourism, exploitation of NTFPs, MAPs and wild edibles from forests, cash cropping.

These weaknesses are aggravated by the lack of clear land use policy, extreme climatic conditions (variabilities and vulnerabilities) and also shift in rainfall and snow fall patterns bringing prolonged flood situations that regularly occur in the region enhancing misery of locals.

4.5 Addressing Threats and Challenges for Addressing Socio-Economic Drivers of Biodiversity Loss

Socio-economic drivers are a set of factors leading to biodiversity loss across the globe but their distance from actual instances of loss both spatially as well as temporally makes it challenging to identify and reduce their impacts by controlling them. Socio-economic forces work cumulatively along with other direct and indirect drivers of biodiversity loss in a complex manner affecting resource use and resource health. Millennium Ecosystem Assessment report (MEA 2005) as well as recently released report of IPBES (Intergovernmental Panel on Biodiversity and Ecosystem

Services) for Asia Pacific in March, 2018 has highlighted that unsustainable production and consumption are important root causes of biodiversity loss, impaired ecosystem services, leading to reduced support to human well being and nature's benefits to people. These reflections are well highlighted and endorsed in global, regional and national biodiversity targets (Aichi Targets), policy formulations and documents so that appropriate actions shall be taken aiming at halting and reversing biodiversity loss (CBD 2012a; Tittensor et al. 2014). References of addressing socio-economic drivers of biodiversity loss have found their place in globally important COP meetings for CBD (Convention on Biodiversity) and also IUCN World Conservation Congresses including the most recent one in Hawaii (2016) and in the UN assessments of IPBES (2015–2018) (Diaz et al. 2015). Concerns of strengthening community conservation efforts are also mentioned in National Biodiversity Action Plan (Government of India 2008). Considering the magnitude of biodiversity loss socio-economic demands in changing climate and to fulfill increased commercial demands needs to be readdressed. The key weaknesses that undermine institutional ability to address the threats and challenges are:

- **Insufficient opportunities for alternative livelihood**
  Study areas located in remote and undulating valleys are having very less opportunities of livelihoods. Traditional agriculture, livestock rearing and forest dependent subsistence lifestyle is insufficient to bring benefits to support good quality of life. Though government has been trying to provide a lot of subsidies as well as giving opportunities for livelihood through MNREGA (Mahatma Gandhi Rural Employment Guarantee scheme) but the involvement is not satisfactory. Present generations are more attracted to lucrative opportunities that can bring them more money in fewer efforts.
- **Restrictions on mountaineering and grazing as livelihood**
  Mountaineering has been banned in most of the high altitude peaks because of them falling in protected forests. Locals earned a significant part of their livelihood from mountaineering being porters or any other mountaineering related livelihood. Before ban being imposed local and indigenous transhumant communities (*Bhotiya* tribes) were traditionally involved in sheep and goat rearing post ban they are devoid of livelihood opportunities. Though, it has been also reported that ban on livestock grazing has also enhanced invasion of exotic plants in alpine areas of Central Himalayas. So, instead of grazing many of them having sound idea of these alpines and pastures are damaging the same areas for illegal collection of MAPs and *Coryceps sinensis.* Major part of these high altitude forest are inaccessible to forest department due to insufficient manpower, complex terrain and geography. Lack of sufficient and well-equipped forest guards is a major issue that needs to be addressed. Less number of forest guards is are insufficient to deter locals from poaching and illegal extraction of resources.
- **Ignoring socio-economics as an important driver of biodiversity loss**
  Sustaining Himalayan ecosystems will require better understanding of socio-economic issues in Central Himalayas and addressing them to target long-term conservation benefits. Locals have been custodians of nature conservation but

lack of ownership and insufficient economic sources is reversing the situation. Role of socio-economic condition of locals in biodiversity loss has been discussed but is unorganized. This scattered knowledge needs to be integrated to understand the influence and cumulative impacts of local socio-economic conditions. Since these forests are efficient sinks for carbon sequestration with immense REDD and REDD+ potential, socio-economic drivers of loss should to be studied in the context of carbon storage and carbon credits that can be sold in voluntary markets and help support locals as vital source of livelihood.

- **Policy concerns**
  The approach to protect and conserve forest resources has always been conserving the areas from living in close vicinity. The rights and human well being of these people have also been ignored. Instead of involving them in conservation they were never considered to be important stakeholders of conservation planning. Implementation of conservation policies has largely overlooked the needs and aspirations of traditional and indigenous communities living around these forests. It has been observed that once a forest area is declared Protected people's rights of resource dependency shrink or are completely removed. It has been given to many corporates (many hydropower projects in the study areas fall in protected core zone boundaries of National Parks, Sanctuaries and Biosphere Reserves) and bigger players. This brings a lot of disbelief among locals about conservation concerns, and efforts of government. In such situations, initiatives to protect forests have resulted into hostile attitudes of local communities towards government, and sometimes leading to significant conflict. This has been commonly observed in locals dwelling in protected area boundaries. Community perspectives are of great priority because no conservation issues can be resolved without community collaboration efforts (Misra et al. 2009).
- **Eco-tourism an alternative opportunity**
  Central Himalayas with high cultural values and rare scenic beauty has potential to uplift economy by generating alternative livelihood opportunities. Many of such locations, nature trails and road connections are either undeveloped or poorly maintained. Opportunities brought by eco-tourism to reduce biodiversity loss and assist communities to earn their livelihood are largely untapped in the study areas (Misra et al. 2009; Maikhuri and Rao 2005).

4.6 Way Forward

Policies for protecting and managing natural resources need to reconsider the socio-economic conditions of local communities dwelling in close vicinity of these forests and providing them better livelihood opportunities. Framing such policies have not been considered because of insufficient understanding or ignorance towards socio-economic drivers and pressures they may exert (Haberl et al. 2007). Over time the governments have considered the sensitivity and importance of forest diversity and deforestation. The have formulated various policies and regulations that are intended to encourage sustainable management and use of forest resources so they can improve local livelihoods and contribute to regional, national and global goals of conservation.

- Harvesting of timber is banned anywhere even in a community owned forest and cannot be carried out without written consent from District Forest Officer. As a measure to control illegal logging, illegally harvested timber is stamped and auctioned by forest department. A forest product declaration form is issued to the timber owner that includes details of timber volume, forest of origin and also tree species.
- **Promotion of agroforestry practices**
  Agroforestry is a prominent part of agriculture fields as all the study areas are maximizing benefits from agriculture. In the region agroforestry continues to contribute significantly to the supply of tree products and ecosystem services. Agroforestry has evolved from traditional retention of useful trees to promotion of fast growing multi purpose trees providing and improving soil fertility, fuelwood, fodder etc. Recently, sink potential of agroforests has attracted a lot of attention of international communities. Agroforestry practices reduce pressure from forests and also helps in supporting and fulfilling green fodder demands during lean winter months. Some of these trees are *Carpus vimnea (Chamkhadik), Celtis australis, Grewia optiva (Bhemal), Sapindus mukorossi, Ficus neriifolia (Thelak,), Debrgeasia salicifolia (Syanru), Boehmeria japonica* etc. While, at lower elevations banana and papaya trees are planted on the bunds of kitchen gardens to check soil erosion that helps in food security and fulfills nutritional demands. India is the first nation in the world to adopt and implement an agroforestry policy. National Agroforestry Policy, 2015 was a farsighted effort to support integration of trees, crops and livestock in agriculture fields. The policy addressed issues related to agroforestry sector and also includes policies, weak markets and a dearth of institutional finance affecting agroforestry in the country. Agroforestry policy is a key step forward to achieve sustainability by harnessing the potential of agroforestry by optimizing agricultural productivity and addressing climate change adaptation.
- **Promoting sink potential of forests involving locals in carbon trading**
  The *Van Panchayat*-managed community forests are reported to have carbon stocks worth 200–280 t c/ha and are potentially sequestering 2–4 tc/ha/yr (CHEA 2009). In present circumstances conserving forest sinks in community forests of the area has not been recognized as a livelihood option. This important regulating ecosystem benefit can help locals to get better benefits in long run under REDD and REDD+ implementation programme. Meeting the targets of Paris COP, 2015 by communities partnering in carbon trading will enhance sink potential of community forests and also help improving socio-economic conditions and addressing conservation targets. Linking the approach to opportunities by making sustainable use of NTFPs and forest biomass for enhancing livelihood for supporting livestock has potential to address out migration as well thereby helping and facilitating organic agriculture in the state.

- **International strategies and interventions**
  There is enough good will from international agencies to support conservation of biodiversity in Central Himalayas. Several agencies such as United Nations Environment Programme, World Bank, Global Environment Facility, United Nations Development Programme, World Wildlife Fund, Asian Development Bank, and International Union for Conservation of Nature have provided financial as well as technical support to the forestry and biodiversity sector in many parts of Central Himalayas. It is most likely that these agencies will increase support and inputs in the region in the future too.

5 Conclusions

In order to improve understanding of above mentioned concerns of biodiversity loss and deforestation in Central Himalayas there is a vital need to understand the conceptual model of socio-economic biodiversity drivers and pressures and do a situational analysis for site-specific locations. Limited numbers of studies have tried to examine how different socio-economic factors interact spatially and temporally at different scales. There is a pertinent need of an all-inclusive and coalescing agenda that can help to address a broad range of socio-economic factors and their complex linkages. Considering the situation from the lens of socio-economy as an important but indirect driver of biodiversity loss the message is clear that underlying drivers of biodiversity loss in the region are complex and many of them also lie outside forestry sector. This study was intended as an analytical approach for a series of case studies that explored a few important socio-economic root causes of biodiversity loss. Examples covered in the study were from different locations of the region, with a variety of environmental and socio-economic conditions. But the only aspect that was common for each location was that biodiversity was threatened by largely by some human activity (some of the activities were driven locally while, some of them were driven by regional, national and international drivers that were out of the geographical area). Socio-economic factors including social, economic, political and governance were observed to be a few of the root causes of these drivers. A few examples elaborating on extraction of species and interlinked rampant loss of habitats enriched our knowledge and understanding of root causes of biodiversity loss. This is going to be a crucial first step in developing effective strategies for biodiversity conservation that help target long term benefits for human well being. Given the diversity of examples, the strategies of conservation need to be essentially wide-ranging. Strategies projected will provide some direction to examples that seek to disclose the relationships among socio-economic factors and biodiversity loss. Recognizing the complexity and the multiplicity of causes and the mechanisms through which fundamental features work it is essential to explore and decipher complexity of drivers of biodiversity loss in the region by facilitating and initiating more research in this direction.

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Forest Resources of Jharkhand, Eastern India: Socio-economic and Bio-ecological Perspectives

Rahul Kumar and Purabi Saikia

Abstract Jharkhand is one of the biodiversity rich states of India because of its origin, diverse physiographic and climatic conditions. It is well known due to its tribal populations, mineral resources, and its vast forest resources. Forest resources are considered as a commodity of high value across the state as most of the locals are dependent for their daily subsistence needs mainly for food and fuelwood. Forests play an important role in the economic, cultural and social lives and supporting rural livelihoods and food security in Jharkhand. Jharkhand is home to tropical moist deciduous and tropical dry deciduous forests and the dominant plant species like *Shorea robusta, Diospyros melanoxylon, Pterocarpus mersupium, Gloriosa superba, Butea monosperma, Madhuca longifolia,* etc. Commonly extracted forest produces are timber, fuel wood, fodder, and a range of Non-Timber Forest Products (NTFPs) such as fruits, nuts, edible fungi, vegetables, fish, animals and medicinal plants, resins, essences, and a range of barks and fibers such as bamboo, rattans, palms and grasses. Over-exploitation of useful plants, lack of knowledge and awareness about the plants' present population status, habitat alteration and specificity, narrow range of distribution, over-grazing are some of the severe threats endangering the existing populations of important plants. Additionally, natural enemies such as pathogens, herbivores and seed predators could substantially limit the abundance of rare plant species in any given area. Collection of plant materials, especially of rare and endangered plant species from natural habitats for various experimental purposes by researchers, also poses a threat on their natural population in the wild. Realizing the continuous depletion of these valuable resources, attempts should be made for its large-scale cultivation and multiplication in order to meet its escalating demand as well as long-term sustainability. There is an urgent need to carry out detailed investigations on the geographical distribution patterns, habitat utilization patterns, feeding ecology, and impact of herbivores on important plant populations.

Keywords Forests resources · Prospects · Challenges · Jharkhand

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1 Background

Forests occupy 1/3 of the earth's land area (FAO 2015) and provide an array of benefits to human societies. These benefits are often described as resources that people can draw upon for fuel for heating, cooking and industrial needs and protect watersheds to enable hydroelectric generation, food security and improved livelihoods, carbon sequestration, climate amelioration, soil and water conservation, recreation, etc. besides their pivotal roles as habitat and environmental regulators. Furthermore, forests play a key role in maintaining water quality, clean air, and help in regulating climate, floods, pollination, biological control of diseases, etc. thus providing various regulating services (Bahuguna and Bisht 2013). Forest is the second largest land use in India after agriculture covering 21.05% of the total geographical area of the country (Anonymous 2011). Forest composition, structure and diversity patterns are important ecological parameters determined by the prevailing environmental and anthropogenic variables (Gairola et al. 2008; Ahmad et al. 2010). Forests play an important role in maintaining important ecological goods and services and their constituent species sustain human life (Daily 1997). They support sustainable farming and human well being by stabilizing soils and climate and regulating water flows. More than 853 million people (49% of total population) use fuelwood for cooking in India (FSI 2011), whereas, in Jharkhand, 57.6% people depend on fuelwood for cooking after Chattishgarh, Tripura, Meghalaya, Assam, Nagaland, Odisha and Manipur. Overutilization of forest resources for fuelwood as well as house construction leads to more than 30% deforestation since the 1990s. Destruction of forests lead to loss of biodiversity, pressure over the fragile ecosystem, ultimately leading to soil fertility loss and erosion as well as too much water runoff into the lowlands. Current estimated global net forest loss is 3.3 million ha yr^{-1} and about 80% destruction is due to agriculture (FAO 2015).

About 85% of the rural population of India utilizes wild plants and its various parts for the diet supplements, livelihood, social upliftment and treatments of various disorders (Farnsworth 1994; Jain 1992). Forests are the key to the economic and socio-cultural life of tribes and provide abode to a large tribal population of India. Tribal communities depend on forests for livelihood and to meet subsistence needs, as tradable goods to generate cash income where market conditions permit, and as raw materials in a variety of processed products (Angelsen et al. 2014). Tribal people are nature loving people who live in harmony with nature and maintain a close link between man and the environment (Sajem and Gosai 2006). Despite the rapid development of mines related industrial sector in the State of Jharkhand over the years, the survival of the majority of the rural people and the tribal population is still dependent on the forests as it provides a variety of NTFPs.

2 Forests of Jharkhand

Forest resource plays an important role in the development of Jharkhand, as a very significant proportion of the population is directly or indirectly dependent on it for their daily household needs. Physiographically, it has four major plateaus separated by narrow steep slopes of which the Chhotanagpur plateaus is most prominent. Jharkhand has been blessed with the rich variety of forests comprising of dry peninsular sal forests, northern dry mixed deciduous forests, moist peninsular sal forests, dry deciduous scrubland, and dry bamboo brake. Dry peninsular sal forests (45.03%) and dry mixed deciduous forests (41.21%) are the major forest types of the state (ISFR 2015) and cover most of the forest area and are home to some of the finest timber producing trees. The total carbon stock of forests in the state is 222.82 million tonnes (817.23 million tonnes of CO_2 equivalent) which is 3.15% of total forest carbon in the country (ISFR 2017). Major forest types of Jharkhand are mentioned in Table 1. The total forest cover of India is 7,08,273 km^2 (21.54%) and the area covered by very dense forests (VDF) is 98,158 km^2 (2.99%), moderately dense forests is 3,08,318 km^2 (9.38%) and open forests is 3,01,797 km^2 (9.18%) (FSI 2017). On the other hand, the recorded forest area of Jharkhand is 23,605 km^2 (29.61%) which is greater than the country's percentage forest cover. The reserved, protected, and unclassified forests are 18.58%, 81.28% and 0.14% respectively. The total forests and tree cover constitutes about 33.21% of the total geographical area of the state (ISFR 2017) which is equivalent to the required 33% benchmark as per the National Forest Policy 1998. District-wise forest cover in Jharkhand is shown in Table 2. Although, the state has lost some of its precious forest covers since its formation, from 2005 the forest cover has slightly increased from 28.34% in the year 2005 to 29.61% in the year 2017. This may be due to large part of demand of industry and local rural populations in terms of timber and fuelwood is met from the tree outside the forests. Table 3 clearly shows that though the forest cover in the state has increased with passing years, the percentage of tree cover has fallen rapidly from 06.29% in the year 2003 to 03.49% in the year 2017.

Table 1 The major forest types of Jharkhand

Forest type	Area (Area in km^2)	Percentage (%)
3C/2e (II) Moist peninsular low-level Sal forest	621.09	2.66
5B/C1c Dry peninsular Sal forest	10,502.80	45.03
5B/C2 Northern dry mixed deciduous forest	9610.48	41.21
5/DS1 Dry deciduous scrub	701.37	3.01
5/E9 Dry bamboo brake	934.16	4.00
Plantation/TOF	954.10	4.09
Total	23,324.00	100

Source FSI (2015)

Table 2 District wise forest cover of Jharkhand

(Area in km^2)

District	Geographical area	Forest cover				% of GA	Change	Scrub
		VDF	MF	OF	Total			
Bokaro	2883	61	232	277	570	19.77	3	38
Chatra	3718	249	864	653	1766	47.50	−8	19
Deoghar	2477	0	14	188	202	8.16	−1	12
Dhanbad	2040	0	44	160	204	10.00	2	20
Dumka	3761	0	259	317	576	15.32	6	44
Garhwa	4093	125	414	851	1390	33.96	−4	62
Giridih	4962	77	339	474	890	17.94	7	28
Godda	2266	13	270	138	421	18.58	7	16
Gumla	5360	305	586	550	1441	26.88	−1	11
Hazaribagh	3555	230	349	772	1351	38.00	1	19
Koderma	2540	81	494	449	1024	40.31	0	5
Lohardaga	1502	174	219	111	504	33.56	2	8
Pakur	1811	3	172	112	287	15.85	0	20
Palamu	4393	57	521	622	1200	27.32	3	98
PashchimiSinghbhm	7224	462	1352	1552	3366	46.59	7	52
Purbi Singhbum	3562	55	592	429	1076	30.21	−1	22
Ranchi	5097	63	364	737	1164	22.84	10	35
Sahebganj	2063	18	258	297	573	27.78	−4	67
Latehar	4291	477	1311	616	2404	56.02	−2	9

(continued)

Table 2 (continued)

(Area in km^2)

District	Geographical area	Forest cover				% of GA	Change	Scrub
		VDF	MF	OF	Total			
Ramgarh	1341	31	110	188	329	24.53	2	18
Saraikela Kharsawan	2657	22	214	337	573	21.57	5	21
Simdega	3774	22	344	875	1241	32.88	0	21
Grand Total	79,716	2598	9686	11,269	23,553	29.55	29	669

VDF Very Dense Forest, *MD* Moderately Dense Forest, *OP* Open Forest
Source ISFR (2017)

Table 3 Comparatively analysis of forest cover and tree cover of Jharkhand from 2001 to 2017

(Area in km^2)

	Year	2001	2003	2005	2009	2011	2013	2015	2017
Forest cover	Very dense forest	11,787	9396	2595	2590	2590	2551	2601	2598
	Moderate forest			9892	9873	9917	9586	9692	9684
	Open forest	10,850	8518	10,235	10,205	10,470	10,450	11,231	11,231
	Scrub	976	749	676	662	683	670	685	668
	Non forest	56,101	55,123	56,316	56,096	56,054	55,444	55,507	55,491
	Total of state's geographic area	79,714	79,714	79,714	79,714	79,714	79,714	79,716	79,672
		29.6%	29.6%	28.34%	28.7%	28.8%	29.61%	29.61%	29.61%
Tree cover	Of State's geographic area	3.4%	6.29%	3.86%	3.8%	3.6%	3.29%	3.49%	3.49%
Forest and tree cover	Total forest and tree cover	25,331	27,728	25,671	25,926	25,891	26,102	26,261	26,475
	Of state's geographic area	31.8%	34.70%	32.20%	32.5%	32.4%	32.74%	32.9%	33.2%

3 Forest Resources of Jharkhand

There are high levels of poverty in Jharkhand, with an estimated 44% of the state population living under the national poverty line (The World Bank 2007). Forests play an important role in the economic, cultural and social lives and supporting rural livelihoods and food security in Jharkhand and provide a wide spectrum of livelihoods for tribal communities in the form of direct employment (engagement in forest department, rural development, agriculture and co-operatives, etc.). Jharkhand has been blessed with plentiful natural resources such as minerals with over 40% of the country's total reserves, forests, fauna, water resources etc. due to it's favourable climatic and topographic conditions (Kumar and Saikia 2018). Forest is an important economic sector contributing a significant amount to the Indian economy. Forest based industries contribute 1.2% of India's Total Gross Domestic Product (Economic Survey, MoF 2011). Forests form a dominant part in the physical, economic and spiritual lives of human population (Byron and Arnold 1999). Agriculture constitutes the main source of livelihood among tribes in India playing a vital role in national economy, rural development, employment and occupation, agro-industries, food and nutrition security, growth and survival, social, economic and cultural conditions and poverty alleviation (Surayya et al. 2008). Forestry is the second largest land use in India after agriculture covering 21.54% of the total geographical area of the country (FSI 2017).The forest vegetation of Jharkhand varies from rich Sal forests to miscellaneous mixed forests and sparsely covered grassland. The floral composition comprises a wide variety of trees, shrubs, herbs, bamboos, grasses, lianas, climbers, creepers, runners etc. and sal dominates with 55% of the total growing stock. Jharkhand is home to tropical moist deciduous and tropical dry deciduous forests, and the dominant trees are *S. robusta* Gaertner f., *Terminalia franchetii* var. *tomentosa* W. Nanakorn, *Madhuca longifolia* var. *latifolia* (Roxb.) A. Chev., *Pterocarpus marsupium* Roxb, *Adina cordifolia* (Roxb.) Brandis, *Diospyrus tomentosa, Buchanania cochinchinensis* (Lour.) Almeida, *Semecarpus anacardium* with occasional bamboo brakes. The common shrubs are *Holarrhena antidysentrica, Nyctanthes arbortristis, Randia* sp., *Casearia species. Indigofera pulchella, Carissa opaca, Wendlandia tinctona, Woodfordia fruitcosa, Croton oblongifolius, Zizyphus* sp. and *Phoenix* sp. Similarly, grasses consist of *Heteropogon contortus, Eulaliopsis binata* and common climbers are *Bauhinia vahilli, Acacia piñata, Butea superba, Milletia auriculata, Smilax* sp. The forests of Jharkhand harbour a rich and varied wildlife comprising mammals, birds, reptiles, amphibians and insects. The dependency on forests is very high because there are 17 tribal districts out of the total 24 (FSI 2017). Jharkhand ranks 6th in terms of scheduled tribe population and 10th in terms of percentage share of the scheduled tribe population to the total population of the state (Jharkhand Economic Survey 2016–17) and tribal people depend mainly on forests and forests products. Tribes and forests have the symbiotic relationship (Saha and Sengupta 2014). Rural families use diverse portfolios of activities to meet basic needs and to improve their standards of living (Ellis 1998). NTFPs play an important role in the livelihoods of millions of rural and urban people across the globe (Areki and Cunningham 2010; Asfaw et al. 2013). Commonly extracted forest produces are timber, fuelwood, fodder, and a range of NTFPs such as fruits, nuts, edible fungi, vegetables, fish, animals and medicinal plants, resins, essences, and a range of barks and fibres such as bamboo, rattans, palms and grasses. The NTFPs provide the products for food, shelter, medicines, fibres, energy and cultural artefacts (Babulo et al. 2009; Belcher et al. 2005; Chauhan et al. 2008) for many of the world's economically backward people. The people living in and around these forests live off these produces which give them succour in times when no other livelihood opportunities and food are available to them. Economic activities, domestic livelihood system and herbal medicines- all are gathered from the forests. Economic benefits include the direct use value of a resource as goods for industry and the consumption good, and its indirect use value is through protecting or sustaining economic activity, and its non-use value to people the satisfaction of the mere existence of a resource, even though they may never see it or consume any product obtained from it (Pearce et al. 1989). Direct use values in forestry resource include timber and non-timber products, but also non-commodity benefits such as forest recreation. Figure 1 shows the importance and values and valuation techniques outlined by Barbier (1994). Indirect use values include the role of forests in protecting watersheds and fisheries and the storage of carbon in forest soil and plants. Non-use values in forestry comprise of non-substantial benefits as the continued existence of certain species of wildlife, which the general public wishes to protect for future generations. The other direct employments consist of labour force for rural masses generated by these departments under regular forestry activities for growth, development and maintenance of the forests, research and training, survey of forest resources, protection and conservation of forest resources, soil and water conservation, harvesting, collection and processing of NTFPs, preparation of nurseries, fencing, soil working, transplanting, planting, tending operations, watering, fertilizer and pesticide applications, protection and management of plantations and infrastructure development. Forests play self-employment service through the sale of firewood and forage, grazing, lopping and grass cutting, forest-based handiworks and cottage industries, sericulture, lac husbandry, beekeeping, charcoal burning, plate making from leaves, liquor making, rope making and basketry, medicines, collection, processing and marketing of NTFPs etc. The application of local skills and village-level technology in wood-based and small-scale forest-based enterprises provide secondary employment and livelihood opportunities for tribal people, notable amongst them are sawmilling, rayon, pulp and paper, plywood and panel products, wood seasoning and preservation, tanning, sports goods, match splints, veneers, wooden boxes, bamboo and cane products, agricultural implements, furniture, structural wooden items, musical instruments, bidi making, educational goods, wood carving, wooden utensils etc. (Pant 1984; Gera 2002) (Fig. 2).

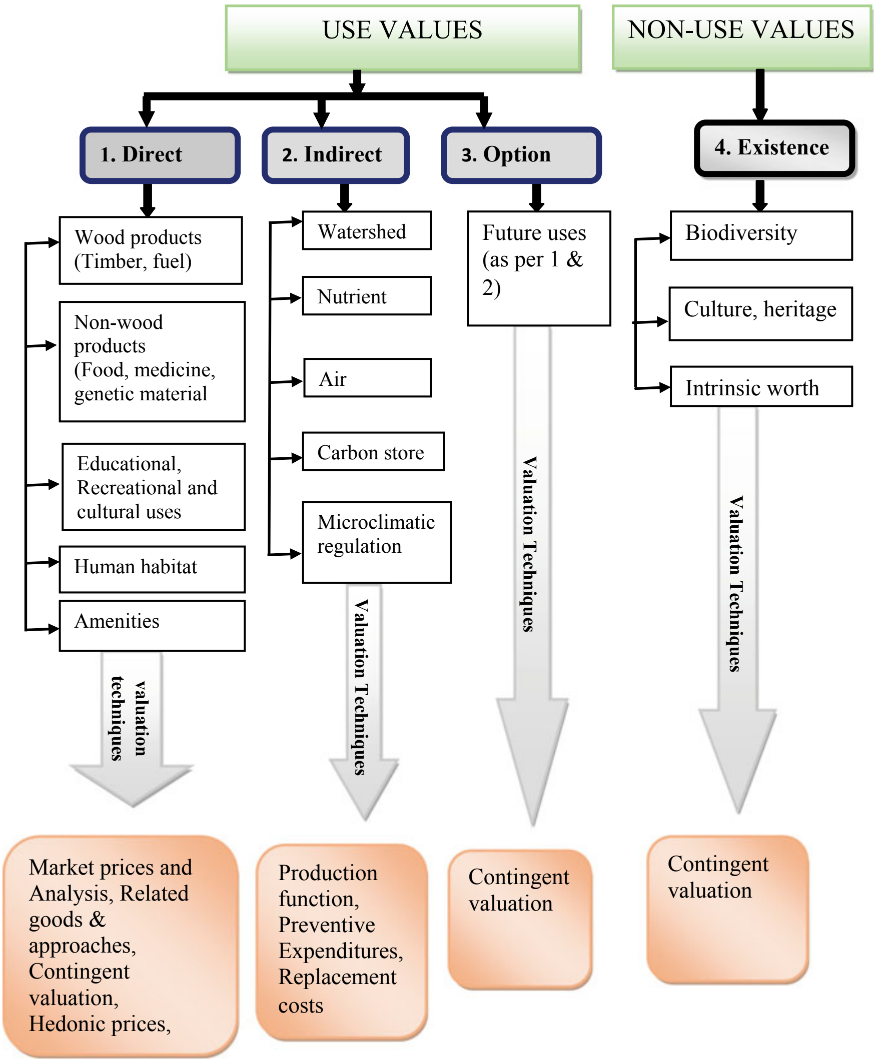

Fig. 1 Importance of forest resource-values and valuation techniques as per Barbier (1994)

4 Economic Prospects of Forest Resources of Jharkhand

The role of the forestry sector to national economies is one aspect of sustainable forest management and information about this is needed to monitor progress in this respect (FAO 2011). Timber, lac and medicinal plants based industries are the main forest-based industries of the state. *S. robusta*, *Gmelina arborea* Roxb. ex Sm., *M. longifolia*, *Dalbergia pseudo-sissoo* Miq., *Schleichera oleosa,* etc. are the main timber species of the state. Plywood and paper industries are of less importance in

Fig. 2 Some important forest resource-based industries

the state as compared to the availability of forest resources. Bihar and Jharkhand together used to play a major role in raw silk production contributing 50% of the nation's total production as a total of 2325 km^2 area in the region is covered by tasar food plants, 90% of which is *S. robusta* and the rest are *Terminalia arjuna* (Roxb.) Wight & Arn, and *T. alata* Heyne ex Roth. Jharkhand is renowned worldwide for its tasar and kuchai silk. Large numbers of commercially important medicinal plants are found in the forests of Jharkhand. The ethnic communities in the Kolhan, Kharsawan and Saraikela regions of West Singhbhum are engaged in the cultivation of cocoons (silkworm) which is one of the major sources of income for them. The state of Jharkhand has a large tribal population of 26.3% with a total of 32 tribal communities (Census of India 2011). The livelihood of tribal population heavily depends upon NTFPs and other forest resources for their nourishment. The Millennium Ecosystem Assessment estimates that up to 96% of the value of forests is derived from NTFPs or Minor Forest Products (MFPs) and services (MEA 2005). More than 5000 commercial forest products are NTFPs, including pharmaceuticals and food. Forests in Jharkhand abound in MFPs, viz., kendu leaves, sal and mahua seeds and leaves; amla, harra, katha, chiraunji; lac; resins; sabai grass; mahua and palash flowers; seeds of karanj; neem and kusum; silk; honey etc. In Jharkhand, kendu leaves trade turnover was to the tune of approximately INR 50 Crore in 2007–2008 and the major portion of which (75%) went to the indigenous people as labour for the collection of kendu leaves. Kendu leaves collection occurs in a short span of two months which is a lean season (April and May) for the villagers. Major NTFPs of the state of Jharkhand is shown in Table 4. Forests are important renewable natural resources generating livelihood requirements for more than 25% of the world's population (Anonymous 2001). Forest resources in Jharkhand are mainly utilized in either on the commercial basis in the form of industries or at the local level by the tribal people for various

Table 4 Major non-timber forest products (NTFPs) of Jharkhand

Botanical name	Family	Popular name of NTFPs	Annual product (approx. in MT)	Main focus area	Availability period (Season)	Produces and uses value added
Tamarindus indica L.	Fabaceae	Tamarind	50,000	Simdega, Chaibasa, Lohardaga, Khunti	February–May	Seedless bricks, paste
Bee sap		Madhu/Honey	5–10	Palamu, Gumla, Simdega, Chaibasa		Food
Pongamia pinnata (L.) Pierre	Fabaceae	Karanj	21	Gumla, Simdega, Chaibasa, Lohardaga	May–June	Antibiotics oil, Spray Ointment, etc.
Madhuca longifolia (J. Koenig ex L.) J.F. Macbr. (seed)	Sapotaceae	Dori	50,000	Gumla, Simdega, Chaibasa, Khunti, Lohardaga, Palamu, Garhwa	June–August	Oil/Soap
Shorea robusta Gaertner f	Dipterocarpaceae	Sal seeds	More than 100,000	Gumla, Simdega, Chaibasa, Lohardaga, Khunti	April–June	Oil/Feed

(continued)

Table 4 (continued)

Botanical name	Family	Popular name of NTFPs	Annual product (approx. in MT)	Main focus area	Availability period (Season)	Produces and uses value added
S. robusta Gaertner f	Dipterocarpaceae	Sal leaves		Gumla, Simdega, Chaibasa, Lohardaga, Khunti	All season except summer	plates
Buchanania cochinchinensis (Lour.) Almeida	Anacardiaceae	Chironji guthli	1000	Palamu, Garhwa, Khunti, Simdega, Giridih, Bokaro	March–May	Dry fruit, used confectionary
Terminalia chebula Retz.	Combretaceae	Mrobalan (Harra)	500	Gumla, Simdega, Chaibasa Lohardaga, Latehar, Ranchi	January–February	Harra powder and Triphala churna
Senna obtusifolia (L.) H.S. Irwin & Barneby	Fabaceae	Chakvar	50,000	Palamu, Garhwa, Latehar, Ranchi	January–March	Medicine
Hyoscyamus niger L.	Solanaceae	Niger seed	1000	Gumla, Simdega, Chaibasa, Hazaribhag, Palamu, Latehar	December–January	Medicine

(continued)

Table 4 (continued)

Botanical name	Family	Popular name of NTFPs	Annual product (approx. in MT)	Main focus area	Availability period (Season)	Produces and uses value added
Mangifera indica L.	Anacardiaceae	Mango Pulp (Amsi)	500	Hazaribhag, Gumla, Simdega, Bokaro, hunti	May–June	Food
Madhuca longifolia (J. Koenig ex L.) J. F. Macbr.	Sapotaceae	Mahua flower	More than 100,000	Most a of Jharkhand	March–May	Wine/Medicine
Boswellia serrata Roxb. ex Colebr.	Burseraceae	Tawar Gond	100	Palamu, Garhwa	March–June	Food
Boswellia serrata Roxb. ex Colebr.	Burseraceae	Gijan Gond	500	Palamu, Garhwa	June–August	Medicine and food
Andrographis paniculata (Burm. fil.) Nees	Acanthaceae	Kalmegh	50	Palamu, Latehar	November–January	Medicine
Woodfordia fruticosa (L.) Kurz	Lathyraceae	Dhawai phool	20	Palamu	December–February	Medicine
Asparagus racemosus Willd.	Asparagaceae	Satawari	50–60	Palamu, Gumla, Khunti	All season	Medicine
Rauvolfia serpentina (L.) Benth. ex Kurz	Apocynaceae	Sarpagandha	10–20	Palamu, Simdega, iridih	September–December	Medicine
Withania somnifera	Solanaceae	Aswagandha	10–20	Gumla, Lohardaga, Palamu	November–December	Medicine

(continued)

Table 4 (continued)

Botanical name	Family	Popular name of NTFPs	Annual product (approx. in MT)	Main focus area	Availability period (Season)	Produces and uses value added
Butea monosperma (Lam.) Taub.	Fabaceae	Palas/Tesuphool	1000	Palamu, Khunti, Simdega, Giridih	March–May	Medicine
Mesosphaerum suaveolens (L) Kuntze	Lamiaceae	Bantuls	400–500	Palamu, Latehar, Garhwa	November–March	Medicine
Schleichera oleosa (Lour.) Oken	Sapindaceae	Kusum	5000	Gumla, Simdega	June–October	Oil/Feed
Mucuna pruriens (L.) DC	Fabaceae	Kaunch beej	40–50	Palamu, Chaibasa		Medicine
Aegle marmelos (L.) Correa	Rutaceae	Bael	50–100	Palamu	March–Ma	Food/Medicine

Source Jharkhand state minor forest produce cooperative development and marketing federation limited (JHAMFCOFED) purposes for livelihood security. The forest biodiversity of the state is under serious threat owing to the uncontrolled grazing, repeated fires, unsustainable harvesting of usufructs, an extension of agricultural fields, habitat destruction and fragmentation by mining, rails, human settlements, dams and encroachment etc.

5 Some Important Forest Resources Based Industries of Jharkhand

5.1 Sericulture (Silk) Industry

India holds 2nd rank as a producer of silk in the world after China. Mulberry, Tasar, Eri and Muga are the four different types of silk used to be produced in India. Tasar culture and related activities have been widely practised in Jharkhand, Madhya Pradesh, Chhattisgarh, Orissa, Uttar Pradesh, North Eastern and sub-Himalayan belts of India for several decades. Jharkhand is the leading producer of Tasar silk and ranks 1st in the country with a production of 2281 MT (80.92% of the total tasar silk produced in India) during 2015–16 (Source: https://community.data.gov.in). Tasar culture is practised by 1 lakh 40 thousand tribal families in the state of Jharkhand, Bihar, Orissa, Chhattisgarh, Madhya Pradesh, West Bengal, Andhra Pradesh, Uttar Pradesh and Maharashtra (Source: Annual report, Central Silk Board Bangalore, India, 2016–2017). Tasar culture is a forest-based industry, which remained as an integral part of the tribal economy in many states of India, employing lakhs of poor and tribal people who have no other vocation. Tribes have strong spiritual, cultural and socio-economic affinity to the forest and to the wild silk moth farming (Goel et al. 2004). Tasar silk is generated by the worm of the silk moth *Antheraea mylitta*. The larvae of *Antheraea mylitta* are polyphagous and feed on various kinds of plant leaves like *T. arjuna* (Roxb.) Wight & Arn, *T. alata* Heyne ex Roth, *Ziziphus mauritiana*, *S. robusta*, *Lagerstroemia parviflora* Roxb. etc. The most dominant tasar host is *S. robusta* (80%) and the rest is *Terminalia* sp. and other host trees (Fig. 3). Only 5% of the tasar food plants in India are put to use for tasar rearing (Singh and Mishra 2003; Remadevi 2005). The tasar silkworms are grown only in the wild; therefore, they are cultivated in places where their host plants are available. Germany is the major importer of tasar silk from India followed by U.S.A., France, Hong Kong, and U.A.E. In order to maintain the leading edge and give special thrust to the sector, Jharkhand Silk, Textile and Handicraft Development Corporation (JHARCRAFT) was established in 2006 to provide support in designing, training, entrepreneurship development, marketing and raw material support in clustered and organized manner by grouping local artisans, self-help groups (SHGs) and non-governmental organizations (NGOs) involved in similar activities.

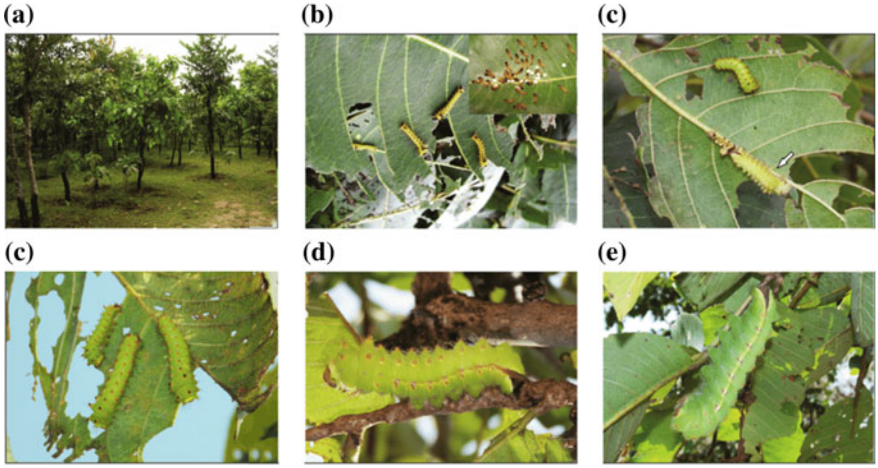

Fig. 3 Rearing of tasar silkworm (*A. mylitta*) showing **a** Host plant (*T. tomentosa* and *T. arjuna*) of *A. mylitta*; **b** First instar larvae, in inset, just hatched first instar larvae; **c** Second instar larvae, newly moulted larva (arrow); **d** Third instar; **e** Fourth instar larva and **f** Fifth instar larva *Source* Gathalkar and Barsagade (2016)

5.2 Lac Industry

Lac cultivation is an important livelihood option for the forest dwellers in different states including Jharkhand, Chhattisgarh, Madhya Pradesh, West Bengal, Maharashtra, Odisha and parts of Uttar Pradesh, Telangana, Andhra Pradesh, Gujarat and North Eastern Hill region (NEH). Besides, it has a high potential for generating employment for both men and women in forest and sub-forest areas. Most of the processing units of lac are located in Jharkhand, West Bengal, Chhattisgarh, Madhya Pradesh and Maharashtra. Lac culture is an economically important vocation practised by many farmers' particularly the economically weak sections. Lac culture, being a labour oriented activity, provides ample opportunity for employment. Employment is generated through cultivation, processing and trading of lac. Lac producers invest their profits for the child education, health, social celebrations and agriculture, local institutions, strengthening empowerment and participation in the local election process in the village (Thomas 2012; Patidar 2011). All natural resins are of plant origin and resin secretion occurs in resin ducts in many plant species with the exception of lac, which is produced by the lac insects *Kerria lacca* (Kerr). The insects are cultured on the tender shoots of several plants such as *Butea monosperma* (Lam.) Taub., *Schleichera oleosa* (Lour.) Oken, *Ziziphus mauritiana* etc. Raw lac is the source of three valuable, natural and renewable products *i.e.* resin, dye and wax. *Rangeeni* and *Kusmi* are the two strains of lac insect which are classified based on the preference of the insect for specific host plants. The big success of lac industry in Jharkhand is mainly due to the availability of its host plants. During the last few years, the efforts in terms of policy, research and development regarding the lac sector percolated at grass root level and interest of stakeholders had got the vital support. It is assumed that there are some bottlenecks hampering the growth of lac production. Table 5 shows lac host plants and their suitability. The highest producer of lac are India, Thailand, Indonesia, parts of China, Myanmar, Philippines, Vietnam, Cambodia, etc. and India is the largest producer of lac with a share of 62% of the world production of 44,000 MT (Ogle et al. 2006). In 1950s, the average production of lac in India was 42,320 tons and an onward decline was noted in lac production during 1970s (52%), 1980s (19%) and 1990s (4%) (Indian Institute of Natural Resins and Gums, Ranchi, Jharkhand, 2015). However, in the revival period during 2000s, a 24% increase was recorded. It is expected that the potential for lac production could increase with India's recent changes in forest policy which encourages the restoration of degraded lands (Sequeira and Bezkorowajnyj 1998). Jharkhand is the biggest lac producing state in India and accounts for more than 50% of the national produce followed by Madhya Pradesh (15%), Chhattisgarh (14%), Maharashtra (9%) and Odisha (4%). Ranchi, Khunti, Simdega Gumla, West Singhbhum, Latehar, Palamau, Garhwa, and Hazaribagh are the main lac growing districts. Lac production scenario in India accounts for over 1000 tons of lac during 2014–15, some leading lac producing districts are presented in Table 6. Out of the 10 highest producing districts, five come from Jharkhand and four of them are top ranked. Out of seven main lac producing districts of Jharkhand, Ranchi holds top rank followed by Simdega, Gumla, West Singhbhum, Palamau, Garhwa, Latehar and others. A survey of production data shows that throughout the last four years (2006–07 to 2009–2010), there has been a negative growth in lac production in Ranchi, Palamau, Garhwa, Latehar and a few other minor lac producing districts. The greatest setback was recorded in Ranchi which witnesses 42.8% negative growth and this district alone contributed around 28.5%. Gumla, West Singhbhum and Simdega districts are known as *kusmi* belt which recorded positive growth ranging from 6.3–29% and these three districts together contributed around 56% of Jharkhand's total lac production. On estimate, around 110 million lac hosts are being exploited in the state. More than 4 lakh families in the state are involved in lac cultivation activity resulting in the creation of 35–40 million man-days per year.

There are several problems associated with lac farming including the scarcity of the lac growers who are mainly tribal. There is no ample and free supply of good quality broodlac by the government and as the lac growers are poor tribal, they cannot procure superior broodlac from the market, especially for *Kusumi* broodlac which is highly expensive compared to *Rangeeni* broodlac. Lac growers are mainly illiterate tribal and they sometimes neglect proper time of lac cultivation which affects the productivity. Due to lack of scientific knowledge on the method of cultivation, they mostly use traditional cultivars. The governmental agency should provide regular training to villagers to lac cultivation in a scientific manner, so they can show interest in lac farming. Sometimes government supplies free instruments, but the supply is insufficient to meet the needs of farmers and partiality is also seen at the time of distribution.

Table 5 List of Lac host plants and their suitability

Sl. No	Host plants	Family	Common name	Strain	Suitable crop
Major host					
1.	*Butea monosperma (*Lam.) Taub.	Fabaceae	Palas	Rangeeni	Summer and rainy
2.	*Schleichera oleosa* (Lour.) Oken	Sapindaceae	Kusun	Kusmi	Summer and winter
3.	*Ziziphus mauritiana* Lam.	Rhamnaceae	Ber	Rangeeni	Premature summer
4.	*Ziziphus mauritiana* Lam.	Rhamnaceae	Ber	Kusmi	Winter
Other hosts					
5.	*Senegalia catechu* (L.f.) P.J.H. Hurter & Mabb.	Fabaceae	Khair	Kusmi	Winter
6.	*Albizia lebbeck* (L.) Benth.	Fabaceae	Siris	Kusmi	Winter
7.	*Archidendron turgidum* (Merr.) I.C. Nielsen	Fabaceae	Galwang	Kusmi	Summer
8.	*Albizia saman* (Jacq.) Merr	Fabaceae	Rain tree	Rangeeni	Summer and
9.	*Croton caudatus* Geiseler	Euphorbiaceae	Putri	Rangeeni	Summer rainy
10.	*Ficus semicordata* Buch. Ex J.E. Smith	Moraceae	Porho	Rangeeni	Summer
11.	*Ficus virens* W. T. Aiton	Moraceae	Putkal	Rangeeni	Summer
12.	*Ficus minahassae* (Teijsm. & De Vriese) Miq.	Moraceae	Dumber	Rangeeni	Summer
13.	*Ficus religiosa* L.	Moraceae	Pipel	Rangeeni	Summer

(continued)

Table 5 (continued)

Sl. No	Host plants	Family	Common name	Strain	Suitable crop
14.	*Flemingia macrophylla* (Willd.) Merr.	Fabaceae	Semialata	Kusmi	Winter
15.	*Desmodium oojeinense* (Roxb.) H. Ohashi	Fabaceae	Sandan or pandan	Kusmi	Winter
16.	*Protium serratum* (Wall. ex Colebr.) Engl.	Burseraceae	Kandeur	Kusmi	Winter
17.	*Ficus virens* W. T. Aiton	Moraceae	Pakur	Rangeeni	Summer
18.	*Ziziphus caracutta* Buch.-Ham. ex Roxb.	Rhamnaceae	Ghont	Rangeeni	Premature summer

Table 6 Top ten lac producing districts in the country during 2014–15

Sl. No	District	States	Quantity (in tons)	Rank
1.	Ranchi	Jharkhand	2530	1
2.	Simdega	Jharkhand	1910	2
3.	Khunti	Jharkhand	1380	3
4.	Gumla	Jharkhand	1330	4
5.	Seoni	Madhya Pradesh	1165	5
6.	Gondia	Maharashtra	1100	6
7.	Balaghat	Madhya Pradesh	882	7
8.	West Singhbhum	Jharkhand	860	8
9.	Korba	Chhattisgarh	750	9
10.	Kanker	Chhattisgarh	510	10

Source At a Glance, IINRS, Ranchi Jharkhand

The climate in Ranchi is warm and temperate. Adverse weather such as excess heat, excess cold, and storm sometimes causes damage to lac cultivation. Insects and animals other than insects are the major enemies cause damages of lac insects. Insect opponents of lac may be predators and parasites. Predators damage lac crops with greater intensity (35% of the total destruction) as they not only drop the population of lac insects but also retard the quality of lac. The vital killers of lac insects are *Eublemma amabilis* (the white moth) and *Holococera pulverea* (the blackish grey moth). Squirrels, monkey, rat, bat, birds (woodpeckers), man etc., are the enemies other than insects which destruct the lac in different ways. More than 20% of lac insect biodiversity reported from the world is found in India. In the face of price fluctuation lac growers' co-operative society would be very beneficial to the cultivators but no steps have yet been taken for setting up such a society in Jharkhand. There is a need to address these problems, so that farmer's confidence is returned and again lac cultivation is taken up in a big way. Indian Institute of Natural Resin and Gums (IINRG), Ranchi, Jharkhand, the only institute devoted to research and development of lac is engaged in conserving the lac biodiversity. Limited availability of broodlac, scattered lac host, poor inter-institution linkages, climate change and involvement of villagers in certain undesirable activities are the cause which resists the growth of lac production in Jharkhand.

5.3 Timber Industry

Timber is a renewable, sustainable, attractive, strong, durable and cost-effective natural building material that combines beauty, superior performance and environmental advantage (Binkley and Earhart 2005; Pirard et al. 2016). Its flexibility and versatility offer a multitude of structural applications such as beams, walls, flooring, cladding, containers, packing cases, formwork, large timber panels, agricultural implements, fencing, hutments, housing, furniture, scaffolding, mine props etc. (Chandramolly 2015; Gangoo et al. 2015). Timber materials have unique aesthetic appeal, provides acoustic, thermal and strength performance, store carbon dioxide and the manufacturing process of wood products requires smaller amounts of energy (Shukla 2003). The demand for timber is met through supplies from government forests and non-forest sources such as farmlands and homegardens (Chandra et al. 2008; Islam 2008). The paradox is that forests produce 70% timber and 30% fuelwood, while the demand for wood is around 70% as fuelwood and 30% as timber (Rai and Chakrabarti 2001). Most of the population in rural, as well as urban sector chiefly depends on forests directly to meet their timber requirement. About 275 million (World Bank 2006) to 350–400 million (MoEF 2009) people living in forest fringes depend upon forests for timber required for agricultural implements, house construction, fencing etc. The extraction and consumption situation of timber in rural sectors plays an important role in the socioeconomic, cultural, religious, ethical, traditional, spiritual, farming and geo-environmental conditions of a region (Dangwal 2005). Increasing trade in timber has supported economic growth and has helped in reducing poverty in a number of developing countries (Anonymous 2016). There is strong evidence that timber plays a significant role in the livelihoods of the world's rural poor to which India is no exception. Collection and selling of timber are the main sources of income for the forest-dwelling population in many countries (Yadav and Basera 2013; Belcher et al. 2015; Langat et al. 2016; Htun et al. 2017). Forests support the local livelihoods as a renewable source of timber and firewood. It is suggested to plan forest resource development strategically so that it augments the rural livelihoods and also supports rural energy requirement. The demand for raw wood by different industries increased from 52 million m^3 in 1998 to 95 million m^3 in 2010 and is projected to

Table 7 Total projected demand for raw wood by different industries in India (in million m^3)

Industry	1998[a]	1999[a]	2000[a]	2005[a]	2010[a]	2015[b]	2020[b]
Paper and paper board	4.48	4.48	4.48	8.96	15.4	26.24	35.84
Construction industry	13.6	14.6	15.9	19.4	22.1	26.3	28.5
Packaging	4.36	4.49	4.62	5.54	6.4	7.55	9
Furniture	2.25	2.38	2.52	3.36	4.62	5.9	7.53
Agricultural implements	2	2.06	2.12	2.33	2.5	2.5	2.5
Plywood	10.1	10.5	11	14	17.96	22.9	29.2
Others	15.21	16.04	17.08	20.32	25.91	31.37	40.23
Total	51.91	54.55	57.72	73.91	98.89	122.76	152.8

[a]Represents actual demand for timber
[b]Represents projected demand for timber
Source Indiastat (2015); the information for the actual demand of wood is available until 2010, and only the projected demand for 2015 and 2020 can be found on the Government of India's regulated site, indiastat.com, which provides secondary level socio-economic statistical information about India, its states, regions and different sectors

increase further to 123 million m^3 in 2015 and 153 million m^3 in 2020 (Table 7). The total growing stock of India's forest is 4498.73 million m^3 and the annual timber production is only 3.175 million m^3 (Nayak et al. 2014). Trees outside forests (TOFs) contribute one-fourth of the total growing stock of the country and have become a major source of timber in India. In the most recent State of Forest Report, the FSI published data on forest cover inside the Recorded Forest Areas (RFAs) of few states for the first time (FSI, 2015). Using this information, along with the data on forest cover and tree cover, the tentative area of TOFs has been assessed for these states and further used in the calculation of growing stock per unit area (Table 8). It has been found that states like Gujarat, Madhya Pradesh and Rajasthan showed a higher growing stock per unit area for TOFs compared to RFAs. In all these years, there has

Table 8 Growing stock per unit area of tree outside forests (TOFs) and recorded forests areas (RFAs) for selected states

Growing stock (m^3 ha^{-1})	TOFs	RFAs
Chhattisgarh	46.15	58.07
Gujarat	83.75	23.38
Jharkhand	**41.07**	**43.94**
Karnataka	46.83	76.96
Kerala	32.65	134.64
Madhya Pradesh	45.25	26.51
Rajasthan	50.86	10.41
Tamil Nadu	46.08	50.72
Uttarakhand	23.30	124.49

Source Calculated from FSI (2015) data on forest cover inside RFAs not been any additional forest biodiversity and productivity, nor has there been any increase in timber production (Puyravaud et al. 2010).

The dependency of tribes on the forest resources for timber has become an integral part of day-to-day life in Jharkhand state, leading to continual illicit extraction. The timber resources support the daily livelihood needs of tribes in terms of housing and fencing materials, poles, utensils, ornamental and decorative purposes, musical instruments, agricultural implements, carving woods, furniture, fuelwood, charcoal, kindling, medicines etc. A site-specific study recorded that the timber accrued Rs. 2185.37 household^{-1} annum^{-1} contributing 7.83% of the total income among indigenous people of Bundu block in Ranchi district of Jharkhand (Islam et al. 2015a). The timber is largely elicited from forests, besides some traditional agroforestry, community forestry and homestead forestry and consumed for packing cases, agricultural implements, furniture, housing, sports goods, cart and carriages building, cattle sheds, storehouses, fencing, scaffolding, ladder and cremation in tribal societies of Jharkhand (Islam et al. 2015b). Widespread poverty and lack of livelihood opportunities often make these people resort illicit over-exploitation of timber from the forests. Hence, with such a huge tribal population and extensive dependence pattern, the overexploitation and unsustainable harvesting have resulted in severe forests degradation, biodiversity depletion and diminished biomass productivity (Islam et al. 2014; Baba et al. 2016). Wasteland reclamation strategy by timber (*G.arborea* and *Tectona grandis)* and bamboo (*Dendrocalamus strictus*) plantations are identified as the best eco-friendly option for timber and bamboo production besides forest conservation and livelihood diversification in Bero Block. The implementation of the proposed strategy would have substantial positive impacts towards social, economic, ecological and cultural security on a sustainable basis. The timber production from the forest has declined due to increased emphasis on forest conservation. To meet their increasing requirements, the wood-based industries have to augment supply by importing wood and promote plantations outside forests in farmer's land of high yielding genetically improved the variety of tree species as well as raise their own captive plantations.

After the 1988 National Forest Policy, the focus on production has shifted from timber to non-timber forest products although timber is the most valuable product of the forests. No reliable estimates are available of timber requirements for house building, furniture, agriculture implements, handicrafts, pulp, paper and other industry. While the requirements of Industry can be worked out from the installed capacity, it is not easy to do so in respect of other important consumers of timber. The large-scale import of timber affects the domestic pricing pattern of timber (GoI 2006), and therefore the import-export policy (EXIM) of the country should be reviewed to rectify the pricing in the market so that it is economically viable to grow trees on farmlands. In the case of India, there is no centralized data pool that maintains timber production records. Additionally, the Ministry of Statistics, GoI mentions the gap in the compilation of forestry statistics in its report on agricultural and allied sector statistics (GoI 2013). The demand of wood continued to increase due to an increase in population and the growing demand for timber products, resulting from the revival of the domestic economy and the rapid expansion of middle and upper-income groups (International Tropical Timber Organization 2003). Generally, the auctions held by the Forest Department report an annual increase in the minimum price (Indiastat 2015). To improve the community livelihoods through timber market systems more space requires engaging in direct timber marketing. The laborious permitting system to remove privately grown high-value trees, such as teak, provides a strong disincentive to the private commercial growing of trees. Alternative policy interpolation through rationalization of transit laws for forest produce is also proposed in order to make it conducive. This scheme aims to boost the growing stock in the despoiled forests by raising quick growing species to meet the future household/industrial/profitable demand of timber by raising plantations of woody species, such as *D. pseudo-sissoo* Miq., *G. arborea*, *T. grandis*, *S. robusta* etc. Besides this, higher efforts are made to plant fruit trees and other energy wood species (http://www.jharkhand.gov.in/New_Depts/ap201011/Forest201011.pdf).

5.4 Kendu Leaves Based Industry

Kendu (*D. melanoxylon* Roxb.) is one of the most valuable NTFPs found in many parts of India, largely distributed in central peninsular India such as Madhya Pradesh, Odisha, Chhattisgarh, Jharkhand, part of Maharashtra and Andhra Pradesh whose leaves are dried and is used for wrapping bidis (a tobacco product know as Indian cheap smoke). Many tribal in Eastern India depend on kendu leaf collection for subsistence and financial lifeline of forests tribal. The tribal collect the kendu leaf as part of their right defined under Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 (FRA). Kendu leaf collection is being associated with rural livelihood and revenue generation for the state. Kendu leaves being an economic resource and livelihood source for the poor, particularly the tribal; it is largely collected and sold for income. Bidi manufacturing is labour intensive, and bidi rolling, which employs the majority of the workforce, is done in almost all major states of India (International Labour Organization 2001). The industry produces between 750 billion and 1.2 trillion bidi sticks per year (Sunley 2008). It is estimated that kendu leaf plucking alone generates about six weeks employment for about 7.5 million people particularly during off-peak agricultural season (Arnold 1995) while rolling bidis engages nearly 4.4 million women and children (Ministry of Labour 2000) resulting in production of 600 billion to one trillion bidis every year in the country (Lal and Wilson 2012). World Bank (2006) reported that kendu leave provides 106 million person-days of employment in collecting activities and 675 million person-days in secondary processing. A study by Voluntary Health Association of India, VHAI (2010) on working condition of people employed in the tobacco-related industry in Bihar, Jharkhand, Madhya Pradesh and Uttar Pradesh found that tobacco collection is very seasonal and over 2 lakh kendu collectors in India are devoid of any alternative means of livelihood for the rest of the year. Jharkhand State Forest Development Corporation (JSFDC) has been nominated as the sole agency

Table 9 Details of Kendu leaves collection and net amount received (2002–2013)

Season of Kendu leaf collection	The quantity of collected Kendu leaves (Standard Sack in lakh)	Amount paid to the primary collector (In Rs. Crore)	Net Amount received by Jharkhand State Forest Development Corporation Limited (In Rs. Crore)	Total received amount (In Rs. Crore)
2002	5.09	20.413	7.680	28.093
2003	3.87	16.491	6.484	22.975
2004	4.74	20.423	6.416	26.839
2005	3.48	15.692	5.619	21.311
2006	3.06	13.978	7.538	21.516
2007	7.5	35.311	15.298	50.609
2008	5.65	28.326	14.862	43.188
2009	5.68	31.299	16.463	47.762
2010	5.68	34.164	20.757	54.921
2011	4.19	27.307	28.256	55.563
2012	7.69	53.906	41.244	95.15
2013	5.29 (On the basis of sale)	47.680 (Estimated)	23.105 (On the basis of sale)	70.785 (Estimated)
2015–16	3.01	32.035	13.38	45.415

Source Jharkhand state forest development corporation limited, Ranchi

for trade in Tendu leaves in the state. It accounts for 75–80% of the total revenue from the forests (Kerketta et al. 2018). It has earned net revenue of Rs. 41.244 crores during the fiscal year 2012–13 (Table 9) and generate employment to the tune of 37 lakh man days.

In Jharkhand, JSFDC is responsible for collection and trading of kendu leaves in systematic and organized manner. For this purpose, the whole forest area of the state is divided into 300 units called lots. Tendu leaves are plucked by the tribal and the 'Munshi' supervises the drying of the leaves. The process of drying takes around 9–10 days after which standard bags are made, each consisting of 1000 bundles. These lots are auctioned to the contractors prior to the collection season. The corporation pays collection prices to the rural people (primary collectors) at a fixed rate every year. In 2015–16 rural people were paid Rs. 1065 for the collection of a standard bag. In measurement terms, 1000 poles make a standard bag with each pole containing 52 leaves. For the Year 2015–16, the corporation collected 3.01 lakh standard bags for which it received an amount of Rs. 45.15 crore. In this process, Rs. 32.035 crore was paid to the primary collectors by the corporation, thus generating an amount of Rs. 13.38 crore for the financial year. Table 10 gives district wise related information of kendu leaves. It shows the production of kendu leaves in the different district of

Table 10 Production of Kendu leaf in Jharkhand, 2009–10 (District wise)

Sl. No.	Name of the district	The notified yield of Kendu leaves (in bSt.bags)
1.	West Singhbhum	44,300
2.	Saraikela-Kharsavan	24,150
3.	East Singhbhum	33,950
4.	Lohardaga	9200
5.	Ranchi	8350
6.	Khunti	16,450
7.	Gumla	8350
8.	Simdega	37,350
9.	Latehar	66,050
10.	Daltonganj	85,500
11.	Garhwa	1,39,875
12.	Hazaribagh	47,400
13.	Ramgarh	2950
14.	Bokaro	27,500
15.	Koderma	17,300
16.	Chatra	1,07,700
17.	Giridih	47,250
18.	Dhanbad	4250
19.	Sahebganj	24,800
20.	Pakur	9200
21.	Deoghar	4600
22.	Dumka	15,900
23.	Godda	9750
24.	Jamtara	3650
Total		7,95,875

Source Jharkhand forest development corporation

the Jharkhand in the year (2009–10). Kendu leaves have contributed between 70–80% revenue to the forest department wherethe economic contribution from kendu leaves to the household is estimated only 2.2–2.7% of the total annual income for the poor (Bahuguna 2000). In such a context, kendu leaf collection rather can be viewed as poverty reduction (Gupta and Guleria 1982; Boaz 2004; Verma and Rehan 2005; Rasul et al. 2008). Saxena (2003) in the case of Odisha, one of the major kendu producing states, notices that since 1990. It is, therefore, Haque Committee appointed by the Union Ministry of Environment and Forest (2011) recommends to give minimum support price for kendu.

From 1st July 2017, as India move in a new system of taxation, the Goods and Services Tax (GST), a centralized tax was enforced on kendu leaf for the first time.

The GST on the leaf is set at 18% with 9% central GST (CGST) and 9% state GST (SGST). Central tax on the leaf was earlier nil. Earlier, only Value added tax (VAT) or sales tax was levied on NTFPs like kendu leaves. But VAT wasn't applied everywhere and it varied from state to state. In Jharkhand, the state had levied 14.4% VAT on tendu, however, in Odisha, the state levied a 5% VAT and 2% forest tax on tendu and in Rajasthan, this figure stood at 5.5% VAT. In the instances, the new SGST is more than the earlier levied taxes. In fact, the total increase in the tax on tendu leaves has skyrocketed, increasing by around 200% in places like Rajasthan, which is a cause of concern for many. Now, as the tax is high, the traders who get the tender from state corporations to collect tendu leaves will pay even less to the tribal collecting the leaves. The remuneration earned is very paltry compared to the hard labour of 14–15 h a day and the workers face acute occupational hazards. Further, it seen that the majority of them want to shift from their present occupations and move to safer alternative means of livelihood. At present most of the tribal work for the tobacco industry as they have no choice due to lack of skills or other employment opportunities. As a result, they are always perennially caught in a cycle of poverty, misery and debt. Paradoxically, kendu leaves plucking being associated with the rural economy and revenue generation activity for the state, on one hand, and its use in wrapping bidi only on the other, there have been discussions among tobacco activists and state policymakers on the matter of reducing tobacco consumption in the country by diverting them towards other alternative livelihood sources. Even some of the state governments prompted to extract kendu leaves for both state and individual benefits through various means (such as insurance and educational fellowships) to retain the right and livelihood of the local people over minor forest produces as envisaged in both Acts mentioned above. However, the discourse still questions the feasibility of extending employment opportunities given the current failure of the government in delivery the existing pro-poor services and employment generation schemes. Thus this paper shed lights on how the livelihood framework, associated with kendu leave collection, entertained with the right of the local people envisaged in various Acts continue to become a detrimental factor toward shifting from kendu leave occupation to others in the line of reducing the burden of bidi consumption in the country substantiating through data collected from five Indian states- Madhya Pradesh, Odisha, Chhattisgarh, Jharkhand and Maharashtra. Despite immense potential of revenue generation and socio-economic upliftment of rural population residing in forest fringe areas limited efforts have been taken up to systematically assess kendu leaf production and impact of silvicultural practices therein (Kerketta et al. 2018).

5.5 *Herbal and Medicine Industry*

Herbal drug plays a vital role in rural areas, and various locally produced drugs are still being used as household remedies for different ailments (Qureshi and Ghufran 2005). Worldwide it is observed that more than 35,000 plant species are being used around the world for medicinal purposes (Sukumaran and Raj 2010) and about 70–80% people around the globe rely on medicinal plants for primary health care (Singh 2002). Plants are an enormous source of medicines, useful in the treatment of various diseases (Bako et al. 2005). Medicinal plants have been used for centuries in traditional healthcare systems and numerous cultures around the world still rely on plants for their primary health care. Traditional herbal remedies with minimum side effects and low cost, people in developing countries like Bangladesh (90%), Myanmar (85%), India (80%), Nepal (75%), Sri Lanka (65%) and Indonesia (60%) have strong belief in this system of medicine (Salam et al. 2016). Plants and plant-based treatments are the basis of several of the modern pharmaceuticals we used today for our various diseases (Abraham 1981; Atal and Kapur 1982). About 80% of the world population relies on traditional medicines for prime health care, most of which involve the use of herbal extracts (Sandhya et al. 2006). In developing countries, more than 80% of the population hangs on traditionalherbal-based medicine, and even in the USA, 25% of the prescription drugs are still based on phytochemicals. Forests signify an important source for local who gather and sell medicinal plants as part of their livelihood (Seth 2003; Adnan and Hölscher 2011). Local healers have significant knowledge, information, and understanding of a wide range of medicinal plants and their formulations and curative properties that are useful to cure the common ailments (Saikia and Khan 2011). Ancient ethnic communities around the world have learnt to utilize their neighbourhood herbal wealth for curative as well as offensive purposes (Subramoniam and Pushpangadan 1995).

The World Conservation Union Medicinal Plant Specialist Group has globally assessed 2,70,000 plant species out of which 33,798 species identified as being at risk of extinction and 380 plant species are registered as extinct in the wild. The World Health Organization has estimated that the herbal market will grow up to 5 trillion dollars by 2050 A.D. at a growth rate of 20% per annum from the present level of 76 billion dollars. Out of this, European Union accounts for about 50%, Japan 16% and USA 11% of share. Asian countries together share only 19% in which India accounts for less than 0.3% of total herbal medicines market (Rastogi and Mehrotra 1990). In India, medicinal plants found from Himalayan to marine and desert to rainforest ecosystems, and almost 95% of the traditional system such as Unani, Ayurveda, Homeopathy and Siddha formulations are based on the plant (Satyavati et al. 1987). India is the world's second largest exporter of medicinal plants after China and both countries together produce more than 70% of the total global demand for herbal products (FICCI 2017). Indian system of medicine has documented 1800 species of medicinal value in which nearly 880 species are being traded in India (Dobriyal and Narayana 1998; Gupta and Chitme 2000). Out of these 880 species, 538 (61%) are extracted from the forest, 88 species (10%) are from cultivation, 212 species (25%) are sourced both from the forest as well as cultivation and 42 species (4%) are imported from different countries (Kumar and Janagam 2011). Domestic demand of medicinal plants has been estimated 1,95,000 MT for the year of 2014–15 while total consumption of herbal raw drug in the country for the year 2014–15 has been estimated 5,12,000 MT. Large numbers of commercially important medicinal plants are common in the forests of Jharkhand as well as grown by the farmers. Jharkhand is lacking for big industries; hence medicinal plants are not utilized so commercially in Jharkhand. More than 1500 ethnomedicinal plants are found in Jharkhand (Barla 2006) and are mainly supplied to the industries in West Bengal. Some selected medicinal plants of Jharkhand (Ansari et al. 2016) are shown in Table 11. The pressure on forest wealth of medicinal plant is too much because epidemiological surveys show preferences by pharmaceutical companies, practitioner and consumers for wild gathered species on the belief that wild plants are more powerful. To ease the existing pressure on traditional forest it is significant to do monitoring of abundance and distribution, assessment of annual yields and records of the harvest practices. The scientifically improved harvesting techniques will lead to better prices for cultivator and also allow recovery time of plants and trees for future harvests. A sizeable number of medicinal plant cultivators have also lost money in investing in the medicinal plantation due to inadequate understanding of volatile dynamics of the herbal industry.

5.6 Sal Plates Manufacturing Industry

Sal leaf is one of the most important NTFPs collected and processed among tribal communities of Jharkhand (Singh and Quli 2011; Bedia 2014). Plate making with sal leaves is a prevailing and widespread household activity for livelihood sustenance among the ethnic people to increase their household income. Sal is worshipped by ethnic people of Jharkhand and they celebrate *Sarhul* festival when new flowers appear in the sal trees and the deities are worshipped with sal flowers (Rasul et al. 2008). Skillfully stitched and pressed sal leaf plates are cheap, disposable, bio-degradable ecological substitute for thermocol and plastic plates and are used locally in the shops, petty hotels, temples, marriage, festivals, etc. They are also preferred by increasingly eco-conscious people and thus there is a great domestic as well as global demand (Champion and Seth 1968). Sal leaf plate making is traditional, less remunerative and incommensurate to labour among Munda, Oraon, and Lohara of Jharkhand (Quli and Singh 2010). Sal leaves are collected mostly by women and children by using 20–25 ft. long pluckers or by picking up the leaves fallen on the forest ground. Generally, twigs with 4–5 leaves are plucked and the leaves are removed from the twigs (Fig. 4a). They go to forest early in the morning and return by 10 or 11 a.m. and this practice is in vogue for about 8 months excluding March and April and July and August. The green leaves are stitched together using small bamboo (*Bambusa bamboos* (L.) Voss. or *Dendrocalamus strictus* (Roxb.) Nees or neem (*Azadirachta indica* A. Juss.) nails into *Pattal* (raw plates) (Fig. 4b). The stitched plates are dried for 3–4 h in an open space under the sun with utmost care to avoid the fungal attack (Fig. 4c). During the rainy season, the plates are sold without drying at very low-prices. The dried plates are packed loosely and are generally transported by bicycle to a nearby market by villagers. Villagers sell plates to either local haat (weekly market) or to a petty trader from there it reaches to different levels of traders and ultimately, it reaches consumers through retailers. Further, poor marketing infrastructure, lack

Table 11 Some important medicinal plants of Jharkhand

Sl. No	Local Name	Botanical Name	Family	Parts used	Medicinal use
1.	Tulsi	*Ocimum tenuiflorum* L.	Lamiaceae	Leaves/Seed	A cough, Cold, Bronchitis, Expectorant
2.	Amla	*Phyllanthus emblica* L.	Euphorbiaceae	Fruit	Vitamin-C, Cough, Diabetes, Cold, Laxative, Hyper Acidity
3.	Ashok	*Saraca asoca* (Roxb.) Willd	Fabaceae	Bark Flower	Menstrual Pain, Uterine, Diabetes
4.	Ashwagandha	*Withania somnifera*	Solanaceae	Root, Leafs	Restorative Tonic, Stress, Nerves Disorder, Aphrodiasiac
5.	Bael/Bilva	*Aegle marmelos* (L.) Correa	Rutaccac	Fruit, Bark	Diarrhoea, Dysentery, Constipation
6.	Guluchi/Giloe	*Tinospora cordifolia* (Willd.) Miers	Menispermaceae	Stem	Gout, Pile, General Debility, Fever, Jaundice
7.	Calihari/PanchanguliaGlori	*Gloriosa superba* L.	Colchicaceae	Seed, tuber	Skin Disease, Labour Pain, Abortion, General Debility
8.	Makoi/Kakamachi	*Solanum nigrum* L.	Solanaceae	Fruit/Whole plant	Dropsy, General Debility, Diuretic, Anti Dysenteric
9.	Sarpa Gandha	*Rauvolfia serpentina* (L.) Benth. ex Kurz	Apocynaceae	Root	Hypertension, Insomnia, High Blood Pressure, Insanity, Hyesteria
10.	Satavari	*Asparagus racemosus* Willd	Asparagaceae	Tuber, root	Enhance Lactation, GeneralWeakness, Fatigue, and Cough

(continued)

Table 11 (continued)

Sl. No	Local Name	Botanical Name	Family	Parts used	Medicinal use
11.	Gritkumari	*Aloe vera* (L.) Burm.f.	Asphodelaceae	Leaves	Laxative, Wound Healing, Skin Burns, Ulcer
12.	Vringraj	*Eclipta prostrata* (L.) L.	Asteraceae	Seed/Whole	Anti-inflammatory, Digestive, Hair Tonic
13.	Rakta Chitrak	*Plumbago indica* L.	Plumbaginaceae	Root, Root bar	Indyspeipsia, Colic, Inflammation, Cough
14.	Kochila	*Strychnos nux-vomica* L.	Loganiaceae	Seed	Nervous, Paralysis, Healing Wound
15.	Neem	*Azadirachta indica* A. Juss.	Meliaceae	Rhizome	Sedatives, Analgesic, Epilepsy, Hypertensive
16.	Benachar/Khus	*Vetiveria Ziziinoides*	Poaceae	Root	Burning, Ulcer, Skin, Vomiting
17.	Mandukparni	*Centella asiatica* (L.) Urb.	Apiaceae	Whole plant	Anti-Inflammatory, Jaundice, Diuretic, Diarrhea
18.	Kaincha/Baidanka	*Mucuna pruriens* (L.) DC.	Fabaceae	Root, Hair, Seed, Leaf	Nervous, Disorder, Constipation, Nephropathy, Dropsy
19.	Dalchini	*Cinnamomum verum* J. S. Presl	Lauraceae	Bark, Oil	Bronchitis, Asthma, Cardiac, Disorder, Fever
20.	Kariyasem	*Mucuna monosperma Wight*	Fabaceae	Stem, leaf	Asthma, Blood Purity, Menstrual Disorder, Urinary Problem, Immunity Booster

(continued)

Table 11 (continued)

Sl. No	Local Name	Botanical Name	Family	Parts used	Medicinal use
21.	Mexican poppy	*Argemone mexicana* L.	Papaveraceae	Whole plant; Seeds; Seedoil, Flowers; Latex Roots; Leaves	Infestation, Skin Diseases, Leprosy, Inflammations, Colic, MalarialFever Wounds, Ulcers. Asthma, Constipation, In Dropsy, Jaundice, Leprosy
22.	Khokali	*Acalyphaindica* Linn.	Euphorbiaceae	Whole plant, roots, leaf	Anthelmintic, Expectorant, Emetic, Hypnotic, Asthma, Pneumonia
23.	Sada Dhatura	*Datura metel* L.	Solanaceae	Seeds, Flowerl	Dangerous level of poison like Tropane Alkaloids Atropine, Hyoscyamine, Scopolamine, which are considered as Deliriants or Anticholinergics

Source Ansari et al. (2016)

Fig. 4 Traditional Sal leaf plate making and marketing **a** Leaf Collection **b** Plate making **c** Drying of plates **d** Packing of plates **e** Transpotation and **f**–**h** Selling at local haat and make–shift shop *Source* Islam et al. (2015a, b)

Table 12 Quantity of sal leaves (ton) used for manufacturing sal plates from different districts of Jharkhand

Sl. No.	District	Quantity (ton)
1.	Lohardaga	15,000
2.	Deoghar	83,500
3.	Sahebganj	44,500
4.	Bokaro	85,000
5.	Hazaribagh	425,000
Total		6,53,000

Source Department of industries, district industry center of concerning district

of availability/access to the storage facilities compels them to sell it in the local *haat* or petty trader. Table 12 is showing sal leaves (ton) in the different district using for manufacturing sal plates in Jharkhand. A huge number of the caterpillar and other insects spoil sal leaves. A heavy rainfall used to wash out these caterpillars and insects from the forests, but due to less rainfall or erratic rainfall during monsoon, the yield is less these days. Sometimes due to improper drying of sal leaves during plate making, fungal attack can destroy plates. The stitched plates are dried for 3–4 h in an open space under the sun with utmost care to avoid the fungal attack. Sometimes fire broke in sal forests and erratic rainfall during the rainy period has also great impact over the sal leave production.

5.7 *Bamboo Based Industries*

Bamboo is a multipurpose and high yielding renewable resource with great economic value and can be utilized in many different manners. Its roots can reduce soil erosion up to 75%, generates more oxygen than equivalent strands of trees, lowers light intensity, protects against ultraviolet rays, sequester CO_2 and is an important atmospheric and soil purifier. On account of extensive rhizome-root system and accumulation of leaf mulch, bamboo serves as an effective agent in preventing soil erosion, conserving moisture reinforcement of embankments and drainage channels etc. (Ben-Zhi et al. 2005). The size of the domestic bamboo economy is Rs. 2043 crore while the market potential is estimated at 4463 crores (Nath and Das 2012). India has a maximum area under bamboo in the world approx. 11,361 km^2 (FAO 2005) with about 130 species belong to 25 genera of the total 1250 species under 75 genera found in the world. Bamboo covers 8.957 million ha of forest area equivalent to 12.6% of the total forest cover of the country (Rai and Chauhan 1998). The domestic demand mainly arises from the use of bamboo in the handicrafts industry, for construction purposes, paper and pulp industry, bamboo flooring, furniture etc. It also generates rural employment (Sharma et al. 2016). Groves of bamboo clumps are relatively common in Jharkhand and gregariously found in the forest areas on the hilly slopes of the plateau region. People use these bamboos for making beds, carpets, baskets, tokri, sup, hand-fans,

Table 13 Quantity of Bamboo as raw materialsfor various bamboo basedindustries from different districts of Jharkhand

Sl. No.	District	Type of forest resource utilized	Quantity in quintal (yearly)
1.	Ranchi	Bamboo	29,000
2.	Dhanbad	Bamboo	25,000
3.	Deoghar	Bamboo	23,000
4.	Sahebganj	Bamboo	–
5.	Kodrma	Bamboo	16,000

Source Department of industries, district Industry Centers of the concerning district

prasad and flowers carriers for temples, packing cases for vegetables and fruits, as a fencing in the fields in order to protect the crops from grazing, hut making, roof making, thatching etc. Bamboos are also used by *Paneris* (beetle leaf growers) as a support system for the framework in the cultivation of battle leaves. Furthermore, bamboo is broadly used as lathis (stick) by the villagers, common men as well as the police personnel. Bamboo is found in abundance in Dumka, Gumla and East Singhbhum districts of Jharkhand. Across the state, mainly in Giridih, Goda, Dumka, Pakud, Sahebganj and Jamtada, training-cum-production centres have provided livelihoods for some 2000 families. The people of 'Kalindi society', a tribe engaged in making bamboo items in East Singhbhum, and the Asur caste natives of Gumla district are trained in making professional products. The appeal and charm of eco- friendly products have captured the international markets and across urban India. Laundry bins, dustbins, decorative items, even furniture are created and readily available markets in urban centres, metros. Rather than the Jharkraft, other small-scale industries (registered in DIC) utilized the bamboo or related with handicraft and handloom. The following Table 13 shows the highest bamboo producing districts of the State.

6 Current Policies, and Programmes to Protect Forests Biodiversity and Improve Livelihood of Tribal in Jharkhand

Some of the policies and programmers to govern the forestry sector of the state are as follows:

- **Tenancy Act** (Bihar, Santhal Paragana and Chotanagpur): These Acts have provisions for the protection of trees also some provisions for regulating unhindered destruction of trees and the promotion of TOF (trees outside forests).
- **Joint Forest Management** (JFM): JFM regulations are meant for eliciting the response of community in conserving the forest and ensuring people's participation in the protection, conservation, and development of forests. JFM is an adaptive

social process, is striving to create sufficient future forests products for sustaining lakhs of the population.

- **Jharkhand Forest Policy and Wildlife Management Plans** (JFMC): The State Govt. predicts a forest sector contribution of 3% to SGDP (State Growth Domestic Product). Restoration of degraded forests, afforestation of community wastelands, cultivated area on private fallow lands, use of suitable technology, environment for resourceful use of forest produce incorporation of JFMC with PRIs and actual benefit sharing and urban forestry are some of the measures the state Govt. is going to take up. Besides, forest-based- revenue development, wildlife management, biodiversity conservation, hygienic environment, and discarded disposal plans are some strategic actions for the management of the environment. The novel forest management planning includes eco-development schemes and also integrates ecotourism that supports manage the forests on scientific manners.
- The State Govt. is anticipating the rights of the forest dwellers available to them through the Forest Right's Act, as it will enable them to start production of agricultural yields on the forest land which will add to the GSDP of the state. Further, it is proposed to help villagers form Self Help Groups (SHGs) to follow forest produce based clean employment collectively, train them and provide the necessary types of equipment for the improvement of their livelihood (www.greenpeace.org).
- Development and Value Addition of Lac and other Gums and Resin: Improving rural income by facilitating extensive cultivation of lac and value addition through processing by villagers through SHGs in lac growing areas of the state (to be marketed through state marketing federation) will be the focus of this scheme (IINRS 2015).
- Central Government through the Ministry of Tribal Affairs (MoTA) has started an ambitious structure for the promoting of Minor Forest Products (MFPs) through the minimum support price (MSP) method to provide a safeguard mainly to the forest dwellers. In Jharkhand state, The Jharkhand State Minor Forest Produce Co-operative Development and Marketing Federation Limited (JHAMFCOFED) have been designated as the State Procurement Agency to carry out this scheme. The scheme will safeguard that the tribal population gets a remunerative price for the produce they collect from the forest.

7 Conclusion

An increase in the population of humans and livestock results in an increase in demand for forest products, and forest land because of the severe decrease in per capita land availability. Indigenous communities in Jharkhand are with the poor socio-economic condition can be improved through efficient utilization of resources, indigenous knowledge, and skills. The NTFPs play a vital role in the rural economy and livelihoods of tribal in Jharkhand and hence employment through NTFPs based value-added industries and their organized marketing system should be promoted.

The bamboo products and marketing have multiple roles to play in the inclusive economic development of the country, especially in the context of the rural population. Plant-derived drugs have an important place in both traditional and modern medical systems and Jharkhand is rich in medicinal plants diversity. It needs further extensive and intensive investigation to suggest a method of conservation as well as the preservation of not only the medicinal plant but also the forest and forests products as a whole. Collection of plant material, especially of rare and endangered plant species from natural habitats for various experimental purposes by researchers, also poses a threat on their natural population in the wild. Realizing the continuous depletion of these valuable resources, attempts should be made for its large-scale cultivation and multiplication in order to meet its escalating demand as well as long-term sustainability. There is an urgent need to carry out detailed investigations on the geographical distribution patterns, habitat utilization patterns, feeding ecology, and impact of herbivores on important plant populations.

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Traditional Agroforestry Systems of Northeast India

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Abstract Traditional agroforests, as one of the integrated approaches to environmental conservation has been considered as a superior system that permits significant and ecological interaction between the woody and non woody components. These traditional systems have been widely practiced by the people of Northeast India since time immemorial. A study has been conducted among three communities viz., Kalita (Assam) and Nyishi and Apatani (Arunachal Pradesh) of Northeast India to understand the structure, economy, soil quality and management aspects of traditional agroforestry systems. The study revealed that the systems have the potential to preserve the plant and animal diversity in different climatic zones of the region. Different plant species grown in these multistoried agroforestry systems are confounded by the livelihood requirements and traditional knowledge. The most prevalent agroforestry systems in Northeast India observed during the study are Agri-horti-silvi-pisciculture, Agri-horti-silviculture and Horti-silvi-pastoral systems. The systems have also been categorized on the basis of economic output viz., Subsistence-based agroforestry system, Semi-commercial agroforestry system and Commercial agroforestry system. Species composition of the traditional agroforestry systems also varied with residue management, soil and climate of the sites. The soil nutrient status of Agri-horti-silvi-pastoral systems shows more favourable soil physical, chemical and biological properties in comparison to other agroforestry systems. An understanding of indigenous practices, therefore, offers excellent opportunities for finding solutions to the problems of self reliance in agricultural development of the region.

Keywords Indigenous · Tradition · Management · Agroforestry · Economic aspect

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1 Introduction

The traditional agroforestry systems are based largely on indigenous knowledge and the species selection, where the farmers grow the plant species of the cultural patterns of the social and traditional significance. Nevertheless, these practices have extended out to marginal and sub-marginal lands due to the growing population pressure. To meet the growing demands for food and small woods, the agroforestry practices are surer way of stabilising productivity and income generation (Arunachalam et al. 2002). So, if planned appropriately, agroforestry has the potential to address a number of land use problems viz., low soil fertility, fodder, fuel wood and timber requirements, and soil and water erosion. The traditional efforts have, however, resulted in food-self-sufficiency and security of the tribal society. This traditional system can therefore act as a substitute to shifting cultivation in addition to promotion and preservation of high agri-biodiversity, both at intra- and inter-specific levels through mixed cropping. The systems also ensure food availability throughout the year through sequence harvesting of the crops (Arunachalam et al. 2002).

Shastri et al. (2002) reported that socio-culturally valued species find place in agroforestry and courtyards traditionally. Supporting medicinal plants cultivation in the traditional agroforestry system is an additive to the livelihood security and in situ conservation of the species. Nonetheless, there are both ecological and economical interactions among different components in these systems (Lundgren and Raintree 1983). Systematic attempts by the Indian Council of Agricultural Research (ICAR) Research Complex for northeastern hill region in 1975 and All India Coordinated Research Project on Agroforestry in different centres of the Institute in 1987 have resulted in development of several models that can be rejuvenated in the sloppy hills. Nonetheless, information on traditional agroforestry practices in the Northeastern part of India is vague, which otherwise is essential for their further improvement and extrapolation to other potential sites. Vegetational cover in agroforestry system impedes the velocity of runoff on soil surface, checks soil erosion, silting and landslides thus reducing the danger of floods. The litter derived from the fallen leaves maintain fertility status of the soil by returning the nutrients. Some improvements required in this system for sustainable soil system is by tightening soil-plant cycle and decreasing nutrient losses that have to be replaced by external inputs. Leguminous cover crop can be used to add nitrogen inputs and to improve soil fertility status that influences soil productivity. In this paper, the more commonly observed traditional agroforestry systems have been discussed and their productivity, sustainability and impact on farm income of three different ethnic communities viz. Nyshis, Apatanis and Kalitas of Arunachal Pradesh and Assam in the northeastern part of India.

2 Traditional Agroforestry Systems

The people of the northeast India have a tradition of cultivating a number of trees, fruit, cereals, vegetables, and rear livestock on the same land since time immemorial. Such practices are known to increase the ecological diversity within a landscape unit and optimize the use of limited resources through the integration of complementary components. The traditional agroforestry is differently practiced by different ethnic groups (Table 1). However, the system can be broadly classified into five different scientific nomenclatures as follows:

Agri-horti-silvi-piscicultural system This is an age-old agroforestry practice adopted by the Kalita community of Assam. This is one of the productive systems, where different agroforestry components are cultivated on the same land management unit. Farming is the mainstay of their economy. The farmers choose the crops and crop combinations based on their own wisdom and perceptions acquired over generations of experiences, the criterion being their day-to-day requirements of food, fuel, fodder and timber (Table 2). The farmers generally plough their field with bullocks. The bullocks, however, incur high cost of feed and fodder. Hybrid varieties of paddy (Ranjit, Bora, Sonalika, Ijong), vegetables (cabbage, carrot, cauliflower, chilli, pumpkin), specific trees, shrubs, and palms are deliberately planted on the cultivated lands. Recently, horticulture has become very profitable and popular because of the improvement in the production potential of edible fruits and timber species like *Musa* sp., *Citrus* sp., *Ananas comosus*, *Bauhinia* sp., *Erythrina indica, Gmelina arborea*, etc. From the socio-economic and cultural viewpoint, some species were maintained and utilized as cash crops. For example, arecanut tree plays a vital role in the economy of the local society. The labour input for managing the crop is less than that for many other crops, which makes it an ideal crop for the people engaged in other occupations. The economic advantage of the system is derived from the cash-sale of the agricultural products. The family income is greatly improved, as the farmers save the cash that otherwise would have been spent on food. The system also provides a more or less full-time employment to most participants who have no other source of income. The farmers also maintain fish ponds in the farmyard. Trees are planted surrounding the fish pond, and crops inter-planted forming an integrated biological production system (Deb et al. 2009). Common carps, silver carps and grass carps are generally preferred by the traditional society. The litter of many leguminous plants like *Leucaena* sp., *Moringa oliefera*, etc. has been found to serve as a good fish-feed when offered as pellets and improved the fish production. Further, the trees and shrubs in the traditional systems play an important role in regulating the microenvironment of the system. They are the principal source of rural energy and provide countless medicinal products used in the households.

Table 1 Economic status of different traditional agroforestry systems

Agroforestry types	Agri-horti-silvi-piscicultural system	Agri-horti-silvicultural system	Agri-piscicultural system	Bamboo-based Silvicultural system	Horti-silvi-pastoral system
Inhabitants	Kalita Group Harmutty	Nyishi	Apatani	Apatani	Nyishi
Village name		Nirjuli and Doimukh	Ziro	Ziro	Nirjuli and Doimukh
Altitude (m asl)	120	118 & 126	1650	1700	118 & 126
Total yield (kg ha^{-1})	10,951	6943	6019	7931	9924
Net return (Rs $month^{-1}$)	6782	3188	5838	2410	5119
Cost-benefit ratio	1:2.8	1:1.4	1:3.4	1:3.1	1:5.9
Profit (%)	73.70	70.83	77.11	75.66	85.55

Table 2 List of traditional agroforestry system with dominant functional component

Species name	Component crop
Kalitas **I. Fruit tree-based**: *Artocapus heterophyllus* Lam., *Mangifera indica* Linn., *Citrus reticulata Blanco*., *Musa* sp., *Ananus comosus* Merr, *Zizyphus jujuba* Lamk., *Cocos nucifera* Linn., *Areca catechu* Linn., *Dillenia indica* Linn., *Elaeocarpus floribundus* Blume., *Citrus limon* (L) Burm.,	**Winter vegetables**: *Brassica oleracea* Linn. Var. *capitata, Brassica oleracea* Linn. Var. *botrytis*, *Raphanus sativus* Linn., *Daucus carrota* Linn., *Coriandrum sativum* Linn. **Summer vegetables**: *Solanum melongena* Linn., *Capsicum annum* Linn., *Cucurbita moschata* Poir., *Momordica charantia* Linn., *Lycopersicum esculentum* Linn., *Luffa cylindrica* Roxb., *Cucurmis sativus* Linn. **Cereals**: *Oryza sativa* Linn, *Zea mays* Linn
II. Bamboo-based: *Bambusa tulda* Roxb., *Bambusa nutans* Wall., *Bambusa pallida* Munro., *Bambusa balcooa* Roxb.	**Cereals**: *Oryza sativa* Linn.
III. Timber-based: *Duabanga sonneratioides* Buch., *Terminalia myriocarpa* Heurek. & Muell., *Michelia champaca., Gmelina arborea* Linn.	**Cereals**: *Oryza sativa* Linn., *Zea mays* Linn. **Vegetables**: *Beta vulgaris* Linn.Var. *benghaliensis*., *Raphanus sativus* Linn., *Solanum tuberosum* Linn., *Brassica campestris* Linn.
Nyishis **I. Fruit tree-based**: *Psidium guajava* Linn, *Mangifera indica* Linn., *Citrus reticulata Blanco*., *Musa* sp., *Ananus comosus* Merr, *Zizyphus jujuba* Lamk., *Carica papaya* Linn., *Areca catechu* Linn., *Dillenia indica* Linn., *Elaeocarpus floribundus* Blume., *Citrus limon* (L) Burm.,	**Vegetables**: *Phaseolus vulgaris* Linn., *Ipomoea batatas* (L) Laurk., *Dioscorea* sp Linn., *Manihot esculenta* Crantz., *Brassica oleracea* Linn. Var. *botrytis*, *Daucus carrota* Linn., *Coriandrum sativum* Linn. *Solanum melongena* Linn., *Capsicum annum* Linn., *Cucurbita moschata* Poir., *Momordica charantia* Linn., *Lycopersicum esculentum* Linn., *Luffa cylindrica* Roxb., *Cucurmis sativus* Linn. **Cereals**: *Oryza sativa* Linn, *Eleusine coracana* Linn., *Zea mays* Linn
III. Timber-based: *Mesua ferrea*., *Duabanga sonneratioides* Buch., *Terminalia myriocarpa* Heurek. & Muell., *Michelia champaca., Gmelina arborea* Linn.	**Cereals**: *Oryza sativa* Linn., *Zea mays* Linn. **Vegetables**: *Beta vulgaris* Linn.Var. *benghaliensis*., *Raphanus sativus* Linn., *Solanum tuberosum* Linn., *Brassica campestris* Linn. **Oil-yielding:** *Sesamum indicum* Linn., *Glycine max* (L) Merr.
Apatanis **I. Fruit tree-based**: *Pyrus malus* Linn, *Pyrus communis* Linn, *Prunus domestica* Linn, *Vitis Vinifera* Linn., *Citrus reticulata* Blanco.	**Cereals**: *Oryza sativa* Linn, *Eleusine coracana* Linn., *Zea mays* Linn
II. Bamboo-based: *Phyllostachys bambusoides* Sieb & Zucc.	
III. Timber species-based: *Pinus wallichiana* A.B. Jack., *Morus laevigata* Wall., *Altingia excelsa* Noron.	

Agri-horti-silvicultural system This is a common and age-old agricultural system practised by the Nyishi community of Arunachal Pradesh. The farmers grow traditional crop species such as paddy, *Eleusine coracana, Zea mays*, etc. in their field. Among the tuber crops, *Manihot esculenta, Dioscorea* sp., C*olocasia* sp. etc. are the most widespread and chief subsidiary food crops. Vegetables grown in the system are *Capsicum*, *Colocasia*, *Solanum tuberosum, Solanum melongena,* etc. Pineapple is a common floor crop grown along with the vegetables in the homesteads. A number of cultivars of banana are also cultivated. The farmers cultivate tree species on the boundary and agricultural crops in the middle. So, this farming practice is predominantly subsistence-oriented. The farmers have poor resource-base, their landholdings are small and fragmented, and they have diverse requirements of food, fodder, fuel and timber. The farmers have a rich tradition of cultivating medicinal plants in their traditional agroforestry systems. In addition, other species that provide leaves, spices and condiments (*Betel vine, Piper longum, Zingiber* sp. *Oscimum sanctum, Azadirachta indica*, etc.) are also cultivated. In practical terms, the main expectation from an intercropping system in a perennial plantation cropping system is that the overall return from a unit piece of land is increased without adversely affecting either the current or the long-term productivity of the perennial crop. At the same time, the returns from the additional crops should justify the adoption of the intercropping practice and should contribute to the long-term productivity of the system.

Agri-pisci-cultural system A stylish land, water and agricultural resource management system is seen among the tribes of 'Apatanis' in Arunachal Pradesh. The conventional societies adopt an exclusive paddy-cum-pisciculture in their field (locally called '*Aji*' system), which is extremely a dynamic system, based on a complex network of irrigation channel and firm water management practices involving the people. The water essential for the rice field are tapped from the nearby streams rising from adjacent catchment areas and steered into the fields through the means of small channels. Paddy is the chief crop cultivated by the Apatanis. They use two local varieties viz, the early and the late growing varieties. The early variety locally called 'Mipya', comprises four sub-varieties like *Pyare*, *Pyapin*, *Pyani* and *Pyat* and the late variety 'Emo', also has four sub-varieties: *Lalang*, *Enkhe*, *Elang* and *Empu*. In general, the agricultural system of the Apatanis is well thought-out to be extremely efficient in this area. The paddy-cum-pisciculture or the *Aji* system of this particular tribe is supposedly recent in origin, being an interaction promoted by the State Government in the mid-sixties. In this system, the local farmers introduce fishes like common carps, silver carps, etc. in the paddy fields. The effectiveness of the fish production in this system, nonetheless seems to be tremendously high. It is worth mentioning here that this outstanding efficiency is despite greater mortality of fingerlings. In addition to paddy-cum-pisciculture system, the Apatanis also grow millets on the bunds sorting out the rice plots as well as raise plots somewhere else.

Bamboo-based silvicultural system This system is also prevalently adopted by the Apatanis. Bamboo is a commercially valuable non-timber species or popularly called as the "poor man's timber" and is common in the homesteads of the Apatanis. For housing they maintain bamboo farms ('Bije') and individual forests ('Sansung'), in totalling to their clan forests. The Apatani farmers grow a sole species of their traditional bamboo locally called 'Apatani bamboo' *(Phyllostachys bambusoides)* in the agroforestry and also in the periphery of the field, which is a native of China and has been introduced in India (Tewari 1992). Despite its socio-economic importance and fast growing nature, information is lacking about its site characteristics, which otherwise can be very useful in introducing this bamboo to similar sites in other parts of the region or elsewhere (Upadhyaya et al. 2008). In the clan forests, the people mainly grow fruit species like apple, grapes, pears, peach, etc. *Pinus wallichiana* is also a component of agroforestry system in the Apatani plateau. These pines are mainly cultivated as timber species for house construction. The Apatanis are more aware of the importance of medicinal plants and they call a meeting from time to time at local level to raise and preserve medicinal plants for future generation. The medicinal plants like *Taxus baccata*, *Illicium griffthi*, *Geranium* sp., *Cymbopogan winterianus* etc. are found in their homegardens. The Apatanis contrasting to their neighbours (the Nyishis) are confining to a narrow territory. The shortage of land has led to the growth of a commendable, efficient and well-managed land use system and water resource management worthy of replication in other areas.

Horti-silvi-pastoral systems This system is practiced by the Nyishis in Arunachal Pradesh. Timber species such as *Terminalia myriocarpa, Gmelina arborea, Mesua ferrea* are grown in combination with the non-timber yielding species like bamboo. *Livistonia jenkinsiana* (locally called 'Toko') cultivation is the unique feature of this tribe. This species is having a greater potential in agroforestry due to its shorter gestation period and recurring economic returns, and the Toko leaves are used as roofing material. The fruit trees like *Mangifera indica, Psidium guajava, Artocarpus heterophyllus,* etc. are common in this system. Crop-animal systems, in which livestock play a multi-purpose role yielded various products and performed different functions, such as recycling of nutrients and energy and helped to achieve self-sufficiency, stability and sustainability of the system, are common among the Nyishis. Most farm families rear cows, bullocks, mithun, chicken and ducks in their homesteads. Some families also rear pigs. The cow forms an important part of the household, not only to provide milk, but also generates organic manure. Increased productivity from livestock will be necessary in these systems to meet the increased demand for animal products, to alleviate poverty and to improve the livelihoods of resource-poor farmers (Devendra and Thomas 2002). 'Mithun' *(Bos frotalis)* is common among Nyishis, which are used for every social and traditional occasion. The biodegradable wastes from houses and the crops are also used as animal feed. The horti-silvi-pastoral land use brings stability in total biomass production through fruit, fodder and fuel wood. During initial period, pasture would contribute most of the income and later the fruit trees. The cost incurred during the preliminary stages would be substantially higher due to warranted performances of all operations like rubbing, ploughing, sowing, planting and use of materials like manure, seeds etc. However, the cost reduces substantially in the next year. The expenditure incurred was mainly on collection of grass, seeds and harvesting of grasses and maintenance of pasture. Horti-silvi-pastoral system has proved to be quite beneficial in generating more income for the farmer especially during off-season when crops are not cultivated. The success of the system largely depends upon the proper selection of fruit tree species under different agroclimatic conditions to meet various objectives. More income could be generated if it is integrated with improved breed of mulch animals (Deb et al. 2009). This system would be more stable if right type of tree and pasture species are grown together. So management strategies have to be improved for this system to get the best return.

3 Economic Aspects of Traditional Agroforestry Systems

In terms of economic condition, the system can also be categorized into- Subsistence-based agroforestry system, Semi-commercial agroforestry system and Commercial agroforestry system. It is observed that Subsistence-based system is practised by the 'Nyishi' community of Arunachal Pradesh. Even homegarden practice of Assam also falls under this category. Basically they adopt this system based on various religious and social beliefs. Jhum or shifting cultivation of Northeast India also falls under this category. Simultaneous growing of 15–20 crops in the same field, as mixed cropping just to fulfil their household needs is the general rule. On the other hand semi-commercial agroforestry system practised by the 'Apatanis' in the high hills of Arunachal Pradesh. Intensive paddy-cum-pisciculture where fish species like silver carps, common carps etc. are intermixed with the paddy. They are fulfilling their own needs and the rest of the products are selling in the market. Commercial agroforestry system are mostly practised by the 'Kalitas' in the plains of Assam, which has been adopted for commercial purpose and is based on tree crops and livestock population. Plantation forestry is an important component of the production system and tree plantations are grown as major cash crops for a range of commercial products that includes fruits trees like *Musa* sp, *Ananas comosas*, *Citrus* sp. and nut bearing trees like *Areca catechu*.

To evaluate the economic feasibility of different agroforestry practices prevailing in the region, a survey was conducted by using questionnaire in four villages each from all the study sites, where local farmers are involved in different agroforestry practices. The results have been summarized in Table 1. Among the five agroforestry systems studied, total yield was highest in the agri-horti-silvi-piscicultural system and lowest in the agri-piscicultural system. However, most of the respondents received their mean annual income from the agroforestry practices irrespective of their financial status. However, the net return was greater in the agri-horti-silvi-piscicultural as the farmers of that area are hard working and utilize most of their time for the plant/crop production. The horti-silvi-pastoral system recorded the highest cost-benefit ratio, while the lowest was in the agri-horti-silvicultural system. Involvement of female members and low input are the important attributes of high net returns in the horti-silvi-pastoral system (Deb et al. 2009). Conversely, illiteracy and non-involvement of female members were responsible for lower net returns and less profit (%) in the bamboo based silvicultural system though the landholding size was large. Further, the 'Nyishi' family size is too large (as a result of polygamy) to sustain with the yield (Deb et al. 2009) and hence the cost-benefit ratio goes almost hand to mouth (1:1). Chakraborty et al. (2015) reported that the mean yearly income in cropland agroforestry income is higher than non-agricultural cropland system. The traditional agroforestry practices also generate employment opportunities to those unemployed people, the activities such as cleaning, pruning, weeding, plucking, binding and counting. Those farmers who had more land use system had to employed 8–15 labours per day especially during harvesting period. The wages amount for employment differs between male and female labours for carrying out these works. Male labours carried out physically and specialized task including plucking, pruning and even for transported to the main area especially in some inaccessible areas where there are no proper roads for vehicles. But for female they are engaged in light work like weeding, mulching, and collecting the products. Some villages the farmers owned livestock farming (mainly poultry, cattle) but this is for minor importance. Some people engaged themselves in other business works as contractor and other exporter trade. The people of both the states of Northeast India have tremendous knowledge to use the natural resources. They collected processes and sells a large variety of non-timber forest products (NTFPs) which include medicinal and aromatic plants (MAPs), bamboo, honey, mushrooms, nuts, tubers, edible worms, insects and leafy vegetables from the forests to fulfil their needs. In Assam, betel leaf is sold to local vendors and the remaining left over is consumed by the family members. Betel leaf is traditionally consumed with slice of areca nut and a thin coating of lime by people of Northeast India.

4 Soil in Different Traditional Agroforestry Systems

Soil conservation is one of the primary benefits of traditional agroforestry systems. The presence of woody perennial in traditional agroforestry system may affect several biophysical and biochemical processes that determine the health of the soil substrate. Soil is the most important natural resources that provide base and support to store water and nutrients required for the growth and development of vegetation, hence, it is the medium of all plants productivity. The soil nutrient status of different agricultural systems was studied in above mentioned agroforestry systems of northeast India, and it was found that all the traditional agroforestry systems had favourable soil physical properties through organic matter maintenance (Table 3). The available nitrogen (N) and phosphorous (P) contents of soil in agroforestry site was maximum in Agri-horti-silvi-pisci culture system and this might be due to good quality vegetation and

Table 3 Physico-chemical properties of soil in different types of traditional agroforestry systems (±S.E., n = 5)

Parameters Parameters	Agri-horti-silvi-pisci cultural system	Agri-horticultural system	Agri-pisci cultural system	Bamboo based silvi-cultural system	Silvi-horti-pastoral system
Texture					
Clay (%)	8.60 ± 0.32	5.06 ± 0.22	7.14 ± 0.29	9.27 ± 0.35	4.90 ± 0.0.18
Silt (%)	10.83 ± 0.29	5.23 ± 0.36	18.39 ± 0.39	7.09 ± 0.14	9.15 ± 0.33
Sand (%) Textural class	80.57 ± 0.64 sandy loam	89.10 ± 0.31 loamy sand	82.16 ± 1.25 loamy sand	85.76 ± 1.58 loamy sand	85.95 ± 0.30 loamy sand
Organic matter (%)	3.81 ± 0.47	4.45 ± 0.51	4.84 ± 0.29	6.42 ± 0.23	4.85 ± 0.40
Total N (%) C/N ratio	0.36 ± 0.01 6.14	0.33 ± 0.03 7.58	0.20 ± 0.04 14.05	0.22 ± 0.04 17.14	0.36 ± 0.00 7.16
Nitrate N ($\mu g\ g^{-1}$)	0.97 ± 0.01	0.77 ± 0.01	0.19 ± 0.01	0.20 ± 0.03	0.91 ± 0. 01
Ammonium N ($\mu g\ g^{-1}$)	8.97 ± 0.03	6.88 ± 0.03	6.53 ± 0.08	4.76 ± 0.14	5.82 ± 0.30
Available P ($\mu g\ g^{-1}$)	29.38 ± 0.72	15.33 ± 0.11	13.80 ± 0.19	13.20 ± 0.36	19.82 ± 0.47

soil management by the people. The farmers cultivate N_2-fixing plants (e.g. *Cajanus cajan, Zea mays* and some pulses) in their system and change the pattern of cropping in every season which helps to sustain their system. In different homeyard system of Assam it was observed that the farmers collect the dead leaves and twigs from the system and dump those detrital below the trees in their agroforestry system, which in due course of time decompose thus adding nutrient content of the soil and enhancing root production. In general soils in the different traditional agroforestry systems are mostly loamy. The concentration of total N, inorganic N (ammonium and nitrate) and available P were greater in the agri-horti-silvi-piscicultural system. This could be attributed to greater litter availability and accumulation, as confounded by higher plants species richness and diversity in this system. Earlier it was reported that the higher fertility status might be due to efficient cycling by the presence of more nitrogen fixing plants in the system (Arunachalam et al. 1997). The bamboo-based silvicultural system registered greater organic matter content in the soil but with low available nutrients, particularly ammonium and nitrate-N. This, perhaps, indicates the availability of less microbial population that does help in ammonification and/or nitrification (i.e. mineralization) as mostly the bamboo residues are sclerophyllous and therefore slow decomposing (Arunachalam et al. 1998). And, the acidic nature of the soil may be due to greater leaching in the soil and also acidic exudates from the pine litter. Juo and Lal (1977) demonstrated that returning crop residues to the soil may reduce the decline in soil N during cropping. Introduction of N_2-fixing trees in the traditional agroforest systems can substantially increase mineral-N inputs. Nutrient turnover from different species are also different. Thus, the agrofrestry systems can lead to more efficient nutrient cycling than other systems and hence to more efficient use of nutrients. It also can control runoff and soil erosion, thereby reducing losses of water, soil, organic matter and nutrients. So it can be used for soil conservation in most of the hilly slopes of the north east region. The favourable effects of traditional agroforestry systems upon soils can be achieved without reducing production, thereby leading to sustainable land use by conserving soil fertility (Deb et al. 2009).

5 Traditional Management Practices

For management of traditional agroforestry system farmers are generally aware especially in summer season when abundant of obnoxious weeds are present in the farmland. They prefer to burn or use biochemicals to suppress the weed growth and their competition with the main crop. The farmers of Kalita community use cowdung and other biofertilizers in their field, which might have enhanced the soil organic matter. They also cultivated N_2-fixing plants like *Cajanus cajan*, *Erythrina indica* and *Bauhinia variegata* mostly in their agricultural field. The farmers of the tribal community are more aware about the management of the system and able to grow more fruit trees than other agroforestry systems. It was also observed that the nursery raising plot of *Oryza sativa* is used for pulses cultivation as the area is considered no more suitable for paddy cultivation for 1–2 years. Pruning and weeding is done and mulches are used properly in the field they believe mulching increases soil fertility. Cleaning and weeding also done two or three times in a year in some agroforestry field depending on the ground vegetation. In many places of Northeast India, it is observed that community after harvesting sugarcane plant, the field is kept as such for one year for regeneration of the same plant from its rhizome. The residue of sugarcane is burnt in the field itself which is considered good for soil health. They feel that burning of the plant residue will destroy all earlier years pathogens from the field, whereas others feel that burning contributes more nutrients to the soil. Faecal matter of poultry and piggery is used for agroforestry field as well as in fish pond in animal based agroforestry systems. Faecal matter of goat is specifically used as fertilizer for Cucurbita and Pumpkin plant. No chemicals applied as the farmers believed that such chemicals deteriorate the soil and unsuitable for betel leaf husbandry. Few plants are used in slope land like cashewnut, pineapple, bamboo, etc. Hill variety of Sugarcane is also used for sloppy land. In Nyishi community farmers prefer to cultivate timber-yielding plants that may have more coarse roots in their field, and they are less aware of biofertilizer application. Poor management practices such as frequent burning and cutting, grazing by animals was also observed in this field. The ashes collected after cooking are also used in the field and on the leaf of brinjal and Cucurbita plant as pesticides. It is observed that the in general fruits are preferred by non tribal community whereas timbers by tribal community. However, the diversity of these traditional agroforestry systems are decreasing day by day due to shortage of land and lacking of traditional knowledge by the younger generation. Therefore, some management approach is required for careful planning on the basis of valuable information, implementation, associated research, monitoring systematic of results and feeding the results of the monitoring back to improved management of the agroforestry system.

6 Conclusion

Maintenance of traditional agroforestry provides a guideline to develop diversified systems that takes advantage of the effects of the combination of plants and animal biodiversity. Such integration enhances complex interaction and synergism that optimizes ecosystem functioning and processes, such as biotic regulation of harmful organism, nutrient cycling and biomass production and accumulation. In an agroforestry strategy, management components are directed to emphasize the conservation and improvement of local agricultural and forest resources, its soil condition by emphasizing a developmental methodology that encourages farmers' participation, use of traditional knowledge and adoption of farm enterprises that fit local needs in socio-economic and biophysical condition. Hence, the goal is to design and improve the traditional agroforestry systems with rich diversity and biological active soil, one that promotes natural pest control, nutrient cycling and higher soil cover to prevent resource losses.

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Agrobiodiversity in Northeast India: A Review of the Prospects of Agrobiodiversity Management in the Traditional Rice Fields and Homegardens of the Region

Tapasi Das and Ashesh Kumar Das

Abstract Agrobiodiversity or agricultural biodiversity has become a major issue in the past few years in light of the growing rate of biological diversity loss and habitat destruction. India is one of the world's largest and oldest agricultural societies and is one of the world's eight centres of crop plant origin and diversity. At least 166 food/crop species and 320 wild relatives of crops have originated here, which include rice, pigeon pea, turmeric, banana, jackfruit, mango etc. Since the agrobiodiversity in South-East Asia is mainly maintained by rural communities in traditional farming systems—homegardens, shifting cultivation and rice fields, the majority of the agrobiodiversity analysis in the tropics have been focused on important traditional farming systems—Home-gardens, shifting cultivation and rice ecosystems. This paper has discussed the concepts of agrobiodiversity, its importance and the threats to its conservation in the context of northeast India. Some case studies on the agrobiodiversity conservation in the traditional home-gardens and the rice fields of the north-eastern region of India are highlighted to understand the status of agrobiodiversity in the region and the problems faced by the farmers. Rice farmers in northeast India maintain a diversity of rice crops which provide them the basis to adapt crops to heterogeneous and changing environments and to provide them with resistance to pests and diseases. Farmers in such traditional agricultural systems have been known to retain 'folk-varieties' also known as 'landraces', 'farmers' varieties', 'local varieties' or 'traditional varieties' which have been bred and selected by farmers. Farmers in such areas maintain their farming systems on the basis of their intimate local knowledge about the rice varieties and their adaptation to specific soil quality and other environmental factors and even retain indigenous soil classification systems (Folk Soil Taxonomy) in their farming systems. Reports from Barak Valley, Assam, India indicate that subsistence based small holder farmers are the main

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managers and conservers of rice diversity with reports ranging from 38 to 25 rice varieties reported from different case studies of which records of traditional rice varieties ranged from 31 to 20. Traditional homegardens which are also an important ethnic agro-ecosystem of northeast India also play an important role in the conservation of agrobiodiversity in the region. Several varieties of fruits, vegetables, medicinal and aromatic plants are conserved in the homegardens of the region. Also there are few reports of wild plant diversity conservation in the homegardens which also have implications for the conservation of underutilized, wild and rare species in the face of the erosion of such species from the adjacent natural forests. However some problems such as land fragmentation, absence of labour, low economic incentives, low return from both the traditional rice farming and homegarden agroecosystem are resulting in a lower diversity of 'landraces' or 'indigenous' varieties. In view of the potential agrobiodiversity in the northeastern region it is essential to properly document them along with the socio-cultural practices and knowledge associated with them before they are lost to the conversion to modern agriculture or urbanization.

Keywords Biodiversity · Plant diversity · Traditional homegardens · Rice farming · Farmers' varieties · Wild diversity

1 Introduction

Agricultural biodiversity, also known as Agrobiodiversity, is a broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agricultural ecosystems, also named agro-ecosystems: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes (COP decision V/5, appendix). Agrobiodiversity or agricultural biodiversity has become a major issue in the past few years in light of the growing rate of biological diversity loss and habitat destruction. The increasing population pressure and the advent of the Green Revolution in the mid 1960s are some of the factors that have contributed to this unprecedented erosion of diversity. The concept of Agrobiodiversity first emerged in 1996 after the "Leipzig Declaration" of the Fourth International Conference on Plant Genetic Resources convened by FAO in Leipzig, Germany. Subsequently in the COP decisions iii/11; the CBD gave specific recognition to Agrobiodiversity (FAO 1998). Agrobiodiversity or agricultural biodiversity is a fundamental feature of farming systems around the world which also includes habitats and species outside of farming systems that benefit agriculture (Thrupp 1997). Agricultural biodiversity is essential to the world for the following functions:

- sustainable production of food and other agricultural products, including providing the building blocks for the evolution or deliberate breeding of useful new crop varieties;

- biological support to production via, for example soil biota, pollinators, and predators;
- wider ecological services provided by agro-ecosystems, such as landscape protection, soil protection and health, water cycle and quality, air quality.

Agrobiodiversity can be considered at three main levels- ecological diversity, organismal diversity and genetic diversity, each forming a hierarchy of elements (Heywood 1995). An important aspect of agrobiodiversity is that it recognizes the great diversity of traditional farming systems and practices in many cultures in different parts of the world and the thousands of species that are locally cultivated or semi-domesticated in homegardens or other polycultures, or harvested from the wild in nearby habitats make a major and essential contribution to food security for hundreds of millions of people across the globe. India is one of the world's largest and oldest agricultural societies and is one of the world's eight centres of crop plant origin and diversity. At least 166 food/crop species and 320 wild relatives of crops have originated here, which include rice, pigeon pea, turmeric, banana, jackfruit, mango etc. Besides the high species diversity in Indian crops the genetic diversity within them is also significant (Kothari 1997). However due to the impact of modernization the traditional agrobiodiversity in the region is also faced with the threat of rapid erosion.

2 Agrobiodiversity in Northeast India

Northeast India comprising of seven states represents an important part of the Eastern Himalaya and Indo-Burma global biodiversity hotspot amongst the 36 recognized global biodiversity hotspots. The Eastern Himalaya region encompasses Sikkim, Assam, and Arunachal Pradesh, whereas the Indo-Burma region encompasses the entire northeastern India, except Assam. The temporal and spatial variations caused by diversity in geological orogeny has resulted into a marked difference in climate and physiography, and consequently in distribution pattern of biotic elements, including the domesticated ones. Also, the spatial position and heterogeneous dispersion of biodiversity elements has caused complexity in biogeographical patterns of the region. The region holds great significance from ecological and evolutionary points of view. A striking feature of the socio-economic profile of the region is prevalence of tribal culture. The region is predominantly inhabited by distinctive ethnic groups (often referred to as "tribals") having unique socio-cultural practices (Arora 1997). Much of the region's agro biodiversity is in the custody of farming communities and tribals who followed age old farming system, including shifting cultivation. These farming communities are the custodians of landrace diversity/economic plant diversity accustomed to meeting their needs under subsistence farming (Arora 1997). This region is rich in biodiversity and harbours largest number of endemics and Schedule I species as compared to any other part of India. The region contributes considerably in the form of wild relatives of several crop plants and domesticated animals. Out of the

22 agrobiodiversity hotspots in India the northeastern India forms 4 agrobiodiversity hotspots.

Since the agrobiodiversity in South-East Asia is mainly maintained by rural communities in traditional farming systems- homegardens, shifting cultivation and rice fields, the majority of the agrobiodiversity analysis in the tropics have been focused on important traditional farming systems—Homegardens (Fernandes and Nair 1986), shifting cultivation (Ramakrishnan 1992) and Rice ecosystems (Dennis 1987). In the present discussion however homegardens and rice fields were considered as the components of agrobiodiversity analysis. Agrobiodiversity maintenance by rural people is not done with a view to conservation but because it is related to their very survival.

3 Agrobiodiversity Management in the Traditional Rice Fields

Paddy rice (*Oryza sativa* L.) is the main crop in the northeastern states. Household food and nutritional security of northeastern states of India predominantly depends on rice. The northeastern region is considered to be one of the hot pockets of rice genetic resources in the world and a potential rice-growing region with extremely diverse rice growing conditions as compared to other parts of the country. Being the secondary centre of origin of rice, the northeastern region is rich in diverse germplasm that shows the distinctness amongst the germplasm which have been collected so far. The widely diverse agro-climatic conditions along with other physiographic conditions have led to immense variability among rice cultivars in the northeastern region (Ngachan et al. 2011). Germplasm survey and collection made so far by the National Bureau of Plant Genetic Resources (NBPGR) from major rice ecologies indicated that about 2000 local landraces are available and it forms about 60% of all rice sown on a small scale by the marginal farmers. The causes of exhibiting wide diversity in rice landraces in the northeastern region may be attributed to the heavy natural selection pressures of diseases and pests, introductions over time and space from adjoining countries, introgression from the wild and weedy relatives, tribal preferences and environmental stresses. Due to a wide range of climatic, edaphic and physiographic conditions the requirement of varieties is diverse. The ecological conditions are ranging from deepwater to high-altitude situation (Hore 2005). Thus, it can be classified into six major classes (Borthakur 1992). These are (i) Autumn Rice (Ahu); (ii) Kharif or Winter Rice (Sali); (iii) Spring or Summer Rice (Boro); (iv) Shallow water (1–2 m) Rice (Asra); (v) Deep-water (2–5 m) Rice (Baon) and (vi) Hill Rice. Such traditional farming systems are important in situ conservation sites of crop diversity. Farmers in such traditional agricultural systems have been known to retain "folk-varieties" (Brush 1995) also known as "landraces" which can be defined as "geographically or ecologically distinctive population (of plants and animals) which are conspicuously diverse in their genetic composition" (Brown 1978). Thus such traditional agricultural systems serve to maintain the landraces (Bellon et al.

1997), 'farmers' varieties', 'local varieties' or 'traditional varieties' which have been bred and selected by farmers. Farmers in such traditional agricultural areas maintain their farming systems on the basis of their intimate local knowledge about the rice varieties and their adaptation to specific soil quality and other environmental factors and even retain indigenous soil classification systems (*Folk Soil Taxonomy*) in their farming systems.

4 Agrobiodiversity Management in the Traditional Rice Fields (Case Studies)

4.1 Chailta Village in Barak Valley of Cachar District, North-East India

The study on the on-farm conservation of rice diversity and local knowledge of soils in traditional rice farming practise of the tea garden labour communities in Chailta village of Barak Valley, Assam was carried out by Das and Das (2004). The traditional rice farming practise in the area (Lowland Rainfed) includes ploughing by bullock or buffalo, transplantation and manual harvesting. In the study site rice is traditionally grown in three well defined seasons, namely Sali (winter rice), Aus (autumn rice) and Boro (summer rice). 40% out of the total 50 farmers were found to cultivate only Sali rice. Of the 50 farmers 20% were found to cultivate in the three seasons-Sali, Aus and Boro. A total of 32 varieties are cultivated in the three cropping seasons in the study area (Fig. 1). Of these 25 (78%) are traditional cultivars and 7 are improved/HYV varieties. The 32 varieties cover an area of approximately 339 bigha of which the traditional cultivars cover more than 50%.

Among the traditional varieties *Chhoeamara* and *Chhatoki* (in Sali rice) are cultivated by maximum number of farmers (50 and 42%). *Chhoeamara* and *Chhatoki* are the two traditional varieties showing the highest relative importance value because of larger number of farmers cultivating these varieties (50% and 42% respectively) and larger land area allotted to the varieties (14.45% and 13.27% respectively). Farmers were found to mostly cultivate more than one variety majority of which are traditional varieties. Farmers gave several reasons for such practise. Firstly varietal diversification help the farmers to adjust to the heterogeneous soil and other environmental conditions, which has also been reported by other workers (Kshirsagar and Pandey 1996; Bellon 1996). Second it is used as a method of reducing the risk of yield loss from exclusive reliance on a single cultivar. Finally, varietal diversification help satisfy a range of demands, for e.g. some varieties may give good fodder yield while others may be much preferred as food. Among the traditional varieties *Chhatoki* and *Chhoeamara* are highly preferred for their eating quality, high volume and red kernel and the two varieties have been reported as the most stress tolerant in terms of soil quality. Other important traditional varieties include *Latoi, Mayamati, Badaal, Ikorjali, Terabali* and *Khoibaruah* which has red kernel and is more energy giving as

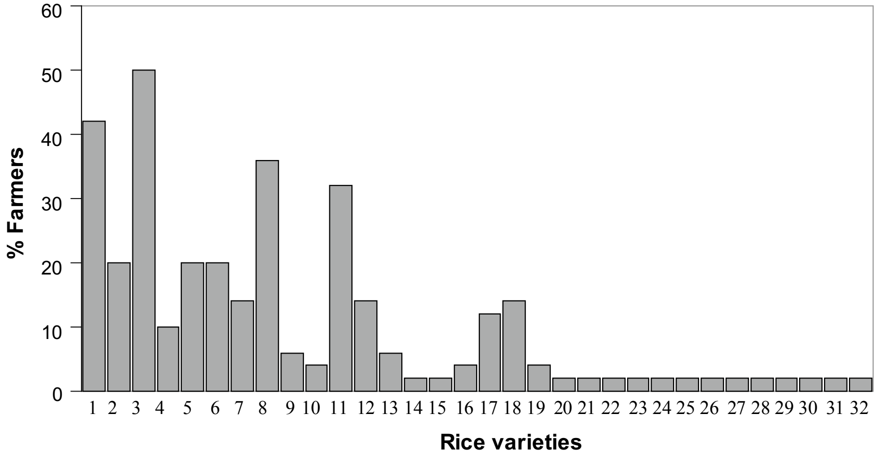

Fig. 1 Rice varieties cultivated by the farmers in Chailta village of Barak Valley, Assam, northeast India. *1 Chhatoki*, *2 Latoi*, *3 Chhoeamara*, *4 Kartika*, *5 Bashphool*, *6 Khoibaruah*, *7 Sailbaruah*, *8 Irri*, *9 Nagrasail*, *10 Biroen*, *11 China*, *12 Mayamati*, *13 Tupasail*, *14 Murali*, *15 Asra*, *16 Pankaj*, *17 Badal*, *18 Ikorjali*, *19 Krishna*, *20 Mohanbaruah*, *21 Bahadur*, *22 Bushibaruah*, *23 Kaiasra*, *24 AusIR8*, *25 Aizong*, *26 Terabali*, *27 Aus Choeamara*, *28 Tupepata*, *29 Gucchibaruah*, *30 Balam*, *31 Agnisail*, *32 IR8*

reported by farmers. Farmers reported that traditional varieties show superior performance in terms of pest resistance, flood resistance and show better adaptation to the variable production environment. They are preferred because of their eating quality, religious value (e.g. *Birain*), traditional food (e.g. *Chhoeamara* for rice flakes), fodder value and commercial value and their adaptation to the traditional pest control and soil fertility management techniques. Religious and medicinal importance has also been reported by farmers for '*Bherapua*' another traditional variety which has become rare in recent times. Some traditional varieties (e.g. *Aizong, Terabali*, etc.) are on the verge of extinction and many important traditional varieties have already become extinct in the village due to non-availability of seed, suitable land and interest towards other varieties. However it is important to mention that it does not mean such varieties have completely disappeared from the valley. Rice farmers in the study village also identified 5 major soil types based on visual surface soil characteristics and ranked them from good to worst based on their suitability for rice cultivation. Thus based on their local knowledge farmers have selected two rice varieties-*Chhatoki* and *Chhoeamara* for Balu soils which was considered to be the worst soil type requiring cultivation of very tolerant rice variety.

4.2 Dorgakona Village in Barak Valley of Cachar District, NorthEast India

The study on the on-farm conservation of rice diversity in traditional rice farming practise of the tea garden labour communities in Dorgakona village of Barak Valley, Assam was carried out by Das and Das (2006, 2014). Rice is traditionally grown in the study area in three well defined seasons. A total of 25 rice varieties cultivated in the three cropping seasons were recorded in the area of which 12 are traditional varieties covering an area of 15.47 ha, which is more than 50% of the total area.

Sali is the most important cropping season in the area and a larger number of rice varieties (20) are cultivated in this season of which 10 are traditional varieties. The large diversity of rice is managed by the farmers as an adaptive strategy to cope with heterogeneous and uncertain ecological and socio-economic environments, including different soil types (Das and Das 2004). The relative importance value for rice varieties in the Sali cropping season (Fig. 2) shows that the *Chhatoki* variety which is a traditional rice variety dominate the rice area. Of the other traditional varieties *Chhoeamara* occupies the second position. These two varieties are highly preferred because of their stress tolerant and eating quality. Farmers cultivating modern varieties were also found to cultivate a traditional variety to spread the risk of crop failure, which was reported by farmers to be often associated with the high yielding varieties.

The diversity of traditional varieties is still maintained by the farmers because of their agromorphological characteristics and traditional ecological knowledge base (Table 1).

Traditional varieties such as *Chhatoki*, *Chhoeamara* and *Khoibaruah* have red kernel and are highly preferred because of their rich taste and high nutrition content (Fig. 3). Varieties such as *Birain* and *Pakhi Birain* are used in the preparation of rice flakes, while *Chhoeamara* is used for preparation of puffed rice. Certain varieties such

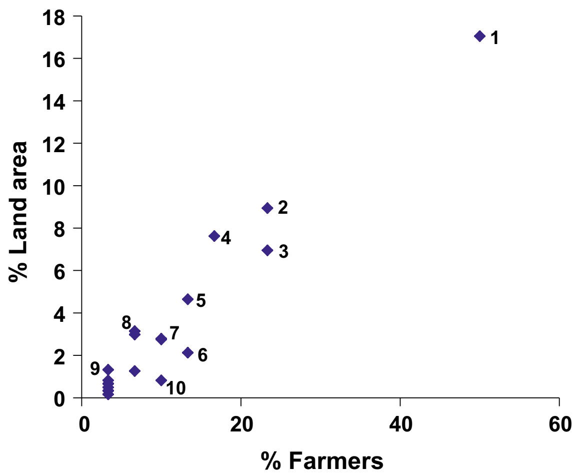

Fig. 2 Relative importance of rice varieties in Dorgakona village of Barak Valley, Assam, northeast India. *1 Chhatoki*, *2 Nagrasail*, *3 Chhoeamara*, *4 Badaal*, *5 Ranjit*, *6 Latoi*, *7 Terabali*, *8 Ikorjali*, *9 Irri*, *10 Birain*. Others *Kartika*, *Pankaj*, *Moinahaal*, *Krishna*, *Baigon Bichi*, *Kaalijira*, *Balam*, *Ranjit*, *Aizong*, *Pakhi Biroen*

Table 1 Characteristics of important rice varieties in Dorgakona village of Barak Valley, Assam, northeast India

Vernacular Name	Important characteristics
LATOI	Fat rice, tasty, moderate yield, high fodder value, can grow in any type of soil
MAYAMATI	Scented sweet rice, red kernel, medium fine rice, good yield. Less pest, can grow in any soil
CHHATOKI (lal)	Red kernel, fat rice, good yield, less Pest, tasty, high fodder value, can grow in any type of soil
CHHOEAMARA	Red kernel, fat rice, sweet and tasty rice, less pest, yield moderate, shattering quality high, fodder value very high, can grow in any type of soil
LAL KARTIKA	Medium fine rice, good yield, can grow in sandy soil
MOINAHAAL	Medium fine rice, scented, tasty, less pest, good yield, can grow in moist fertile soil
TERABALI	Very fine rice, yield good, less pest, commercial value high, can grow in athali + balu soil
BALAM	Round fat rice, yield high, can grow in athali soil
KALAJIRA	Very small and fine scented rice, medicinal, yield good, very high commercial value, can grow in athali type soil that is less fertile
BAIGON BICHI	Very small fine rice, yield good, medicinal value, can grow in clayey soil
BERAPUA	Scented fine rice, cultivated for religious purpose, medicinal, high commercial value, pest resistant, can grow in moist blackish soil
KAALA BIRAIN	Red kernel, fat rice, used in festivities for pancakes and rice flakes, can grow in athali soil
LAL BIRAIN	Red kernel, tasty and fat rice, yield good, used in festivities for pancakes and rice flakes, can grow in athali soil

as *Bashphoo*l and *Kaalijira* are also preferred for their scented aromatic character. Many traditional varieties find use as indigenous medicine. Varieties such as *Baigon Bichi* are used to revive sick people. The potent medicinal value of the variety and the resultant high commercial value is an important factor in farmers' decision to cultivate the variety. Also mentionable is the variety '*Berapua*' which is rare in the village and has high commercial and medicinal value besides being of religious importance. Farmers reported that traditional varieties show superior performance in terms of pest resistance, flood resistance and show better adaptation to the variable production environment. Farmers' selection of traditional varieties is based on its performance in the field, its yield and its tolerance to stress. Farmers in the study area have a deep knowledge about the characteristics of the traditional varieties and its performance under different environmental stresses. Based on their knowledge and preferences they continue to match cultivars to different environmental conditions in the field while discarding varieties with inferior value for a particular set of qualities such as yield, adaptation to soil quality etc. In this context farmers reported two varieties *Chhatoki* and *Chhoeamara* to be the most stress tolerant.

Fig. 3 Seeds of traditional rice varieties with food value in Dorgakona village of Barak Valley, Assam, northeast India. *1 Badaal*, *2 Baigon bichi*, *3 Berapua*, *4 Chhatoki*, *5 Chhoeamara*, *6 Kaala mekuri*, *7 Lal kartika*, *8 Latoi*, *9 Moinahaal*, *10 Terabali*, *11 Khoibaruah*

An important aspect in the management of crop diversity is the seed flow and traditional seed storage systems. Seed flow in the area especially for land races happens as farmers exchange seeds among themselves within the same village, purchase seed from market or collect it from other farmers or relatives while travelling (Fig. 4). The farmers in the area have their own seed storage systems or traditional seed bank

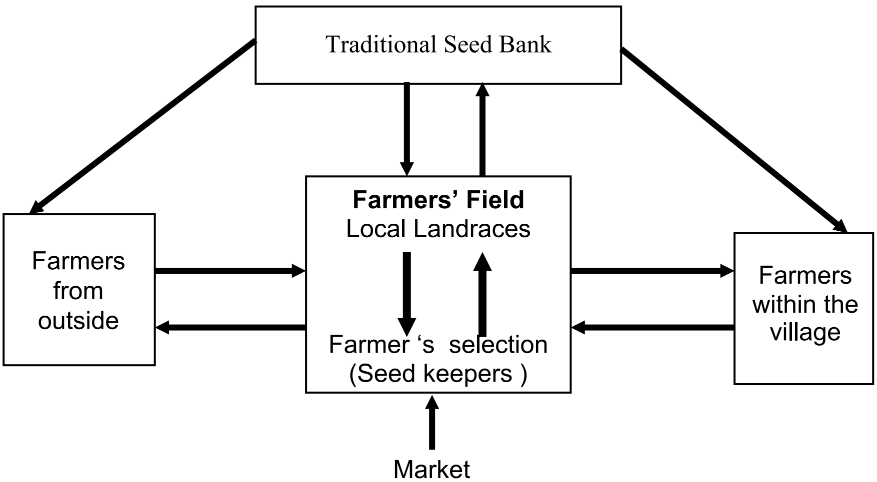

Fig. 4 Traditional seed flow

Fig. 5 Farmers' seed bank and seed storage system

(Fig. 5). Farmers on the basis of performance and preference select the varieties to be stored for seed. Selection of seed is done after harvesting.

The grains from the upper portion of the healthy plant are usually separated by hand, foot or by beating with a stick and then sun dried for a day and stored. Storage for each variety is done separately in order to facilitate their identification and allocation to specific field conditions. Storage is done in bamboo baskets (*dol/tukre*) or in godown (*Machan/Ugaar)*. The storage devices are made airtight by covering the mouth with straw and a mixture of cowdung and mud. The whole structure is also plastered with the mixture of cowdung and mud. Such storage systems remain pest free in majority of the cases and the viability of the seeds remain intact. These storage systems are the farmers' *own seed bank*.

5 Agrobiodiversity Management in the Traditional Homegardens

Homegardens can be defined as "land use system involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock within the compounds of individual houses, the whole tree-crop animal unit being intensively managed by family labour" (Fernandes and Nair 1986). Homegardens are a component of agrobiodiversity at the agroecological level. Homegardens are the closest mimics of natural forests in their structure and usually have 3–4 vertical canopy layers. Homegarden diversity is especially notable in areas where there is a high degree of socio-economic and socio-cultural variability such as northeast India (Ramakrishnan 1992). Northeast India, having rich ethnic and cultural diversity, gives rise to diverse homegarden structures where important plant species are maintained to fulfill various needs. Traditional homegardens in the rural landscape form an important ethnic agroecosystem. Diversification of crops is a traditional practice of the ethnic communities and is critical for the sustenance of marginal households during environmental uncertainty. The crops grown in homesteads are consumed for subsistence needs. Homesteads are the basic units of agrobiodiversity and the custodians of seed banks of a large number of horticultural/fruit/tuber crops, and they often provide significant economic benefits to marginal farmers. Home gardens not only maintain but also sustainably improve crop diversity, thus making these extremely significant areas for the use and conservation of agrobiodiversity.

6 Agrobiodiversity Management in the Traditional Homegardens (Case Studies)

6.1 Dorgakona Village in Barak Valley of Cachar District, NorthEast India

In a study of 50 homegardens of tea garden labour community from Dorgakona village in Barak Valley of Cachar district, northeast India by Das and Das (2005) a total of 122 trees and shrubs have so far been identified in the homegardens with 87 tree species. Average number of species per homegarden varies with the size of the homegardens. In smaller homegardens, the lowest of eight species were recorded, with more dominance of fruit trees with multiple uses such as *Artocarpus heterophyllus*, *Mangifera indica*, *Musa* sp. etc. In larger homegardens, a maximum of 39 species were recorded and are important sites for the conservation of wild/rare species like *Aquilaria malaccensis*, *Vatica lanceaefolia*, etc. besides other fruit and timber trees. The homegarden size and diversity were found to be related to the socio-economic conditions of the families that maintain them. Poorer families with no or less paddy land holdings had smaller homegardens and therefore less diversity. On the other hand, tea garden labourers with larger families and more earning members had larger homegardens (0.13–0.53 ha). The species relative importance values (RIV; Table 2) show that the most dominant components in homegardens were *A. catechu* (52.7%), *Musa* sp. (22.2%), *A. heterophyllus* (9.4%) and *M. indica* (9.3%). Other important species of homegardens include *T. ciliata*, *Psidium guajava*, *Carica papaya*, *Citrus maxima* and *Cocos nucifera*. The species that have multiple uses as well as commercial importance showed higher RIV due to higher prevalence in homegardens. Eight major plant use categories were identified in the homegardens. Figure 6 shows the mean number of species in each use category per homegarden with the dominant one being the fruit category, followed by timber and miscellaneous. The fruit trees were dominated by *Artocarpus heterophyllus* and *Mangifera indica*. In the timber category the most dominant were *Toona ciliata* and *Syzygium cuminii*. In addition to providing food some fruit trees are multipurpose and play an important role in festivals and rituals. An important characteristic of the homegardens was the predominance of indigenous fruit trees. Among the fruit trees importance is given to *Artocarpus heterophyllus* and *Mangifera indica*. The villagers cultivate different varieties of *Artocarpus heterophyllus* and *Musa* sp. Besides the common fruit trees, the villagers also greatly value certain wild/lesser known fruit trees, such as *Artocarpus chama, Artocarpus lacucha,*

Table 2 Relative Importance Values (RIV) of dominant homegarden plants in Dorgakona village of Barak Valley, Assam, northeast India

Frequency of occurrence	Species	Life form	Uses	RIV (%)
90% (very common)	Beetel (*Areca catechu*)	Palm	Fruit/cash	52.73
	Banana (*Musa sp.*)	Tree	Fruit/cash	22.24
	Jack fruit (*Artocarpus heterophyllus*)	Tree	Multipurpose	9.37
	Mango (*Mangifera indica*)	Tree	Multipurpose	9.32
70–90% (common)	Cedrela tree (*Toona ciliata*)	Tree	Timber	6.66
	Guava (*Psidium guajava*)	Tree	Fruit	5.08
	Shaddock (*Citrus maxima*)	Tree	Fruit	4.82
	Papaya (*Carica papaya*)	Tree	Fruit	4.92
Bamboo sp.	*Bambusa cacharensis*			100.34
	Schizostachyum dulooa			27.41
	Meloccana baccifera			24.66
	Bambusa vulgaris			22.42
	Bambusa balcooa			21.77
	Bambusa nutans			3.40

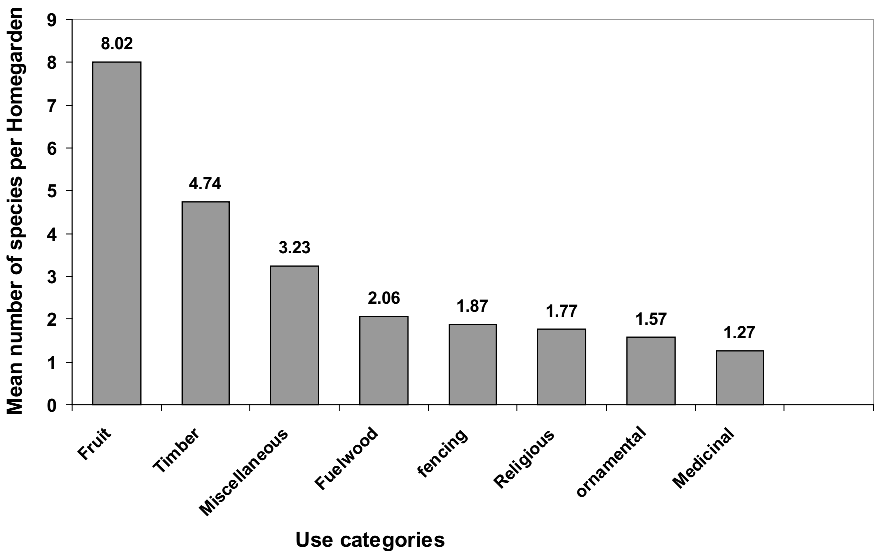

Fig. 6 Mean number of species per use category per homegarden in Dorgakona village of Barak Valley, Assam, northeast India

Garcinia sp., *Licuala peltata* etc. many of which can be labelled as 'Cinderella' tree species, as they have been overlooked by science and the products of such species have been collected, gathered and utilized by villagers and are still of enormous importance to the rural people (Leakey and Newton 1994).

Bamboo forms an important component of farming system in the study area and are often managed in a separate zone or land known as bamboo groves (*Bansh tilla*). Based on their utility and preference farmers have prioritized *Bambusa cacharensis* with multiple uses (construction, agricultural and fishing implements). Many of the products from this bamboo are sold in local markets as a source of additional income. This is followed by *Bambusa vulgaris* and *Bambusa balcooa*, which are also important raw material for paper industry besides other uses. Homegardens are important sites for in situ conservation of plant diversity and can also serve as gene pools for the eroding indigenous tree species. Many wild rare tree species like *Aquilaria malaccensis, Vatica lanceaefolia,* are also conserved in the homegardens because of their high commercial value and it is to be mentioned that the management of *Aquilaria malaccensis* in the homegardens is often used as an indicator of social status among the villagers. Other important rare species conserved include *Caryota urens* and *Licuala peltata.* Homegardens are also the sites for the preservation of underutilized edible species like *Baccaurea sapida, Flacourtia jangomus, Garcinia* sp., *Meyna spinosa* and *Spondias pinnata.*

6.2 Rajubari Village in Barak Valley of Cachar District, NorthEast India

In a study of 36 homegardens of Meitei Manipuri from Rajubari village in Barak Valley of Cachar district, North-East India by Devi and Das (2010) a total of 92 species (38 trees, 10 shrubs, and 44 herbs) belonging to 43 families were recorded. Nine use categories of plant species have been recorded in the studied village. Vegetables formed the predominant category followed by fruits and medicinal plants. The households exchanged/shared vegetables such as *Parkia timoriana* and other legumes among friends and neighbours. The other utility classes, e.g., timbers, ornamental, sacred plants and spices, although important, comprised only of a few species per category. *Parkia timoriana* was ubiquitous in the homegardens and is one of the important trees which is conserved from generation to generation by the Meiteis. Bamboos are generally grown in the backyard or away from other plants. Four species of bamboos were recorded viz. *Bambusa balcooa, B. cacharensis, B. nutans* and *B. vulgaris*. Bamboo has multiple uses in the village economy. It is used for making a vast array of household items and agricultural implements, and the young shoots are used as food. Among the four species, *B. balcooa* is the most important and was present in 78% of the homegardens. It is used as weaving equipment by the Meitei women and also used for construction of houses and for fencing. The study revealed the diversity of plant species being managed in *Ingkhol*, the traditional homegardens of Meiteis in Rajubari village.

6.3 Barak Valley of Assam, NorthEast India

In a study of 181 homegardens from 38 villages in Cachar, Hailakandi and Karimganj districts of Barak Valley, northeast India by Das and Das (2015) a total of 161 tree species from 47 families were identified. Native species comprised of 155 or 86% of the total number of species. Out of the total of 161 tree species recorded 39.13% belonged to the timber use category followed 21.12% under the fruit use category (Fig. 7).

Indigenous multipurpose trees such as *Artocarpus heterophyllus* Lam. and *Mangifera indica* L. were encountered in more than 70% of the homegardens in the three districts. Bamboo is an important component of the homegardens and found to be present in majority of the sampled homegardens and is often managed in a separate zone known as *Bansh jhar* (Bamboo grove). 5–7 bamboo species were recorded from the different homegardens in the three districts of Barak Valley, Assam. Differences were recorded for the priority bamboo species in the homegardens of the

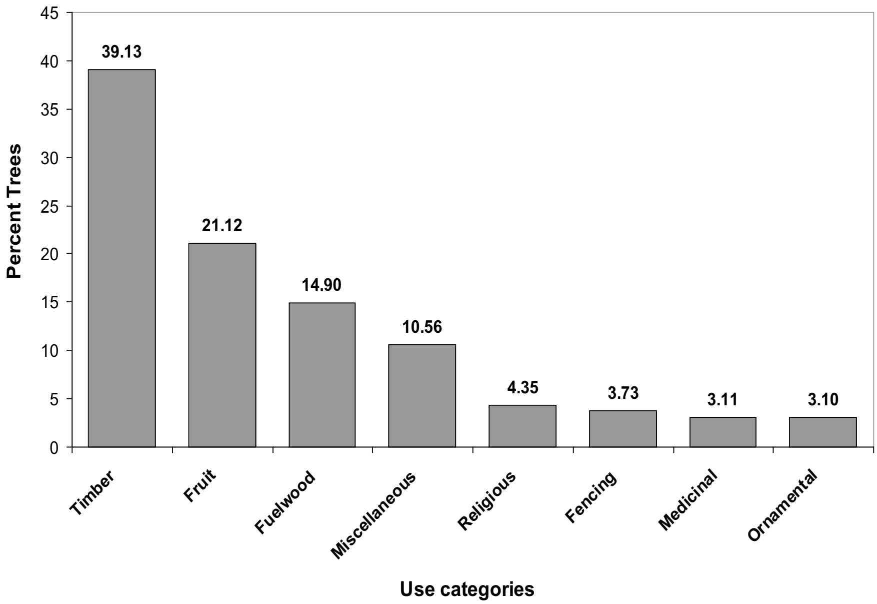

Fig. 7 Percentage distribution of recorded tree species to different use categories from the homegardens in Barak Valley, Assam

three districts. A total of 20 shared species were recorded from the homegardens of the different cultural groups. Certain species were found to be unique to the different cultural groups in the three districts. *Parkia timoriana* (A. DC.) Merr., is one such species which is distinct to the Manipuri community and at least one individual of the species was encountered in majority of the Meitei Manipuri homegardens (Fig. 8). *Leucaena leucocephala* (Lam.) de Wit, is a species whose fruits are edible as vegetables and is unique to the Bishnupriya Manipuri community in Cachar district (Fig. 9). Larger number of unique tree species was recorded from the homegardens of the tea garden labourers which included species such as *Alphonsea ventricosa* (Roxb.) Hook. f. & Thomson, *Castanopsis indica* (Roxb. ex Lindl.) A.DC., *Castanopsis purpurella* (Miq.) N.P. Balakr., *Chaetocarpus castanicarpus* (Roxb.) Thw., *Citrus medica* L.,

Fig. 8 *Parkia timoriana*

Fig. 9 *Leucaena leucocephala*

Garcinia kydia Roxb., *Palaquium polyanthum* (Wall. ex G.Don) Baill., *Saurauia roxburghiia* Wall., and *Sterculia foetida* L., including bamboo species such as *Melocanna baccifera* (Roxb.) Kurz., and *Schizostachyum dullooa* (Gamble) Majumder. Variations in composition and diversity were observed for the homegardens owned by different cultural groups. Ethnicity plays an important role in explaining the differences in species composition and richness although the statistical relation found is very poor in terms of the values obtained from multiple linear regressions. Higher homegarden sizes were recorded for the tea garden community in the three districts and lower sizes were recorded for the homegardens of the Burman community. The largest number of species was recorded from the homegardens of the tea garden labour community followed by the high altitude Khasi community. Farmers' selection and maintenance of species diversity in the homegardens is not done with a view to conserve but because of their multiple uses and long term product benefits. The homegardens were also found to be an important repository of underutilized trees like *A. chama*, *Baccaurea ramiflora* Lour., *C. grandis, Garcinia* spp., *Meyna spinosa* Roxb. ex Link., *Spondias dulcis* L., *Spondias pinnata* (L.f.) Kurz., and *T. ciliata*. Homegardens were also found to be sites of conservation and preservation of naturally regenerating forest tree species, especially for the homegardens of the tea garden labourers in the Valley, such as *A. chama, A. lacucha, A. malaccensis, Chrysophyllum lanceolatum* (Bl.) DC., *Dysoxylum binectariferum* (Roxb.) Hook. f., *G. kydia, Licuala peltata* Roxb., *Saraca asoca* (Roxb.) Willd., *Streblus asper* Lour., and *Zanthoxylum limonella* (Dennst.) Alston.

7 Conclusions

The discussion of the case studies on the traditional rice farming systems and homegardens from the different regions of northeastern India clearly highlight the role of traditional communities in the conservation of agrobiodiversity in their traditional farming systems. A large diversity of indigenous and native rice and plants exist in such traditional farming systems of the various rural pockets of northeast India including the region of Barak Valley, Assam. This diversity of rice and plants is managed because of the farmers' preference and use of them and further highlight the concept of the 'conservation through use' approach which is an element of a complementary conservation strategy and there is an urgent need to strengthen and document such traditional system of natural resource management for economic viability, ecological sustainability and social acceptability. The traditional ecological knowledge of the different ethnic communities plays a pivotal role in the management of agrobiodiversity in the traditional rice fields and homegardens. The traditional knowledge of the different communities which have been passed from generation to generation is reflected in their homegarden design and their management strategies of their traditional farming systems. However some problems such as land fragmentation, absence of labour, low economic incentives, low return from both the traditional rice farming and homegarden agroecosystem are resulting in a lower diversity of 'landraces' or 'indigenous' varieties. For the traditional homegardens the threat is the growing importance given to cash crops such as *Areca catechu* leading to the increasing dominance of such plants in the homegardens. In the case of rice farming systems it is the increasing interest in the HYV due to absence of proper farming techniques, land fragmentation and failure to successfully transfer the related traditional knowledge to the next generation. In view of the potential agrobiodiversity in the northeastern region it is essential to properly document them along with the socio-cultural practices and knowledge associated with them before they are lost to the conversion to modern agriculture or urbanization.

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Medicinal Plant Biodiversity in India: Harnessing Opportunities for Promoting Livelihood and Food Security

Sunil Nautiyal, K. C. Smitha and Harald Kaechele

Abstract India's rich biodiversity is distributed across its ecological regions. Traditional medicinal plants are recognised for their value and they constitute source of livelihood and food security for large Indian population. Cultivation of medicinal plants is also a source of income; thereby improve the standard of living for local communities and reduce poverty. Yet, today Indian medicinal habitat and ecosystem are going through tremendous pressure for meeting the requirement of various pharmaceutical and aroma-chemicals related industries. The objective of this paper is to synthesis the existing information on current status; explore the potential opportunities and constraints in medicinal plant cultivation in India. Based on the documentation of two cases i.e., Bhotiya tribe of Central Himalayan Region and Soliga tribe of Biligiri Ranga-swamy Temple Tiger Reserve (BRTTR), an attempt has been made to suggest a framework for harnessing medicinal plant cultivation for promoting food security in India. Finally, SWOT analysis of medicinal plants and food security in India has been presented.

Keywords Medicinal plants · Biodiversity · Bhotiya tribal community · Soliga tribal community · Food security

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1 Background and Context

Ayush (Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homeopathy[1]) is ancient system of medicine has evolved through ages and has been recognised as formal health system in India. In fact, Indian health care system evolved through Ayurveda[2] system.[3] As Per the reports, Ayush has turnover of Rs. 120,000 million comprising of micro, small and medium based enterprises (MSMEs) accounting for more than 80% in India[4] (GoI 2011; Planning Commission 2011). AYUSH sciences though constitutes traditional form of medicine yet it has not received much attention and recognition constrained by the factors such as deterioration of resource base, unsustainable harvesting, imperfect informal marketing strategies, slow pace of modernisation, fragmented industry, lack of standardisation, inadequate R&D, absence of marketing and branding, inadequate emphasis on HR, unregulated trade etc. Further, an AYUSH science is yet to be recognised as Medical and Health Care Sciences (ibid) in India. Recent steering committee report (2011) on AYUSH[5] identified four major thrust areas of improvement for 12th Five Year Plan but has conspicuously missed out on the strategies of developing medicinal plant clusters in the rural areas.

India is one of the 12 mega biodiversity countries in the world having two among 34 biodiversity hotspots. India accounts for 8% of the total global biodiversity with an estimated 49,000 species of plants of which 4900 are endemic (Maiti 2004; Kumar and Asija 2000 in Ramakrishnappa n.d). Indian Medicinal Plants[6] thrive on 15 Agro-climatic zones consisting of 17,000–18,000[7] species of flowering plants of which 6000–7000[8] are documented systems of medicine (like Ayurveda,[9] Siddha, Unani and Homeopathy)[10] accounting 50% of all the higher flowering plant species of

[1]Out of 17,000 medicinal plant species, 2000 plant species are used for Ayurveda, Siddha and Unani systems of medicine (Planning Commission 2000). Another study point that four streams of Ayurvedic, Unani, Sidha and Tibetan use approximately 4500 medicinal plants (Shukla and Gardner 2006).

[2]By 1998, roughly it was estimated that the turnout of Ayurveda industry was Rs. 45 billion (Subrat 2002).

[3]A classical stream of medicine known as ‘Ayurvedha’ system is the one of the ancient and perhaps the oldest (6000 BC) among the organized traditional medicine which was taught in the ancient universities such as Nalanda (ibid).

[4]India caters to 12% of the world’s medicinal plant requirements.

[5]India’s ancient Rig Veda which dates back to 4800 and 1600 BC is the earliest record on the use of tree, shrub, herb and grass combinations for curing ailments (Lambert et al. 1997).

[6]Please refer (http://nmpb.nic.in/) for more details on Indian Medicinal Plants.

[7]50% of them i.e., 8000 are inventoried as consisting medicinal value (Subrat 2002).

[8]According to ‘All India Coordinated Research Project on Ethnobiology (AICRPE) during the last decade recorded over 8000 species of wild plants used by the tribals and other traditional communities in India for treating various health problems’. Accessed from: (http://www.indiahomeclub.com/botanical_garden/endangered_medicinal_plants_in_india.html).

[9]Classical medicine such as ‘Ayurveda’ can be found in philosophical texts such as ‘Charka Samhita, Sushruta Samhita and Bhela Samhita (Planning Commission 2000).

[10]These are expressions of codified medicine system in India (Dhar et al. 2000).

India.[11] About 960 species of medicinal plants are estimated to be in trade of which 178 species have annual consumption levels in excess of 100 metric tonnes. According to the Botanical Survey of India, at least two third out of 45,000 plant species recorded are potentially of medicinal value (Subrat 2002; Hegde 2003; Nautiyal et al. 2015).

Particularly the region of Himalayas[12] and North-eastern region[13] is widely known for its rich medicinal and aromatic plant biodiversity consisting of 2500 (213%) medicinal species (Hegde 2003; Maiti 2004; Kala et al. 2006; GoI 2011; Uniyal 2015). Indian medicinal plants[14] are rich source of traditional medicine[15] and herb industry providing livelihood and health security for large Indian population.[16] In fact, medicinal plants form the basis of socio-cultural, spiritual, traditional or indigenous health care system from local medicines and herbal practices in hilly regions and among tribal and folk communities[17] in India. Ayurvedic[18] formulations use combinations from around 1200 species out of which 500 are commercially traded (Subrat 2002; Hegde 2003). It is estimated that there are over 6 lakh licensed and registered alternative medicine practioners in India (Hegde 2003). But, today Indian medicinal plants face the threat of extinction due to habitat loss to developmental projects,[19] competition, rapid climate change and over-collection. An estimated

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[11]India has a rich protected area network comprising of 8 designated biosphere, 87 national parks, 447 wild life sanctuaries, 140 botanical gardens encompassing rich biotic diversity including medicinal and aromatic plants (ibid).

[12]Himalayan region consisting of Himachal Pradesh is endowed with 3000 plant species with 500 have medicinal properties. Similarly, Arunachalpradesh consists of more than 500 species (CUTS 2004). The region of Himalayas constitutes 18% of the total geographical area of India, spanning 12 states in India. The region is endowed with Himalayan Biosphere Reserve (Nanda Devi), four National Parks and six Sanctuaries (Nautiyal et al. 2005). As per the Exim Bank report (2003), nearly 18% of traded medicinal plants of India and 350 out of 960 mostly used species is from the Himalayan region (Banerji and Basu 2011).

[13]Northeastern region comprised of eight Indian states covering an area of 2,62,060 km^2 representing 8% of the Indian total geographical area (Uniyal 2015).

[14]May 22, 2004 is declared as 'International Day for Biological Diversity. UN Secretary General message on May 22, 2004 states that '"Biodiversity: Food, water and Health for All" which "underlines biodiversity's importance in ensuring food security and … in protecting wide array of traditional medicines … based on world's biological riches".

[15]Traditional Health Care constitutes two systems namely folk medicine and codified system of medicine (Dhar et al. 2000).

[16](ibid).

[17]Such stream of inherited traditions is known as Local Health Traditions (LHT) (Planning Commission 2000).

[18]70% of share in the formal medicine market is shared by Ayurveda drugs. By 2002, there were about 6000 licensed units and equal number of unlicensed units working on Ayurveda drugs (Subrat 2002).

[19]Development projects like expansion of roads, creation of Special Economic Zones (SEZs), intense mining activities, housing projects etc.

316 species in India are under threat of extinction.[20] In addition, traditional medicinal practices took a back seat due to advancement of allopathic medicine (western medicine). New guideline based on WHO-IUCN-WWF consultation in Thailand (1988) has eventually led to the 'Chiang Mai Declaration' calling for action to 'save plants that saves our lives'. It is comprising of eight Indian states covering an area of 2,62,060 km^2. and represents 8% of the country's total geographical area. Further, international organisations like UNDP, IDRC, OXFAM, WHO, Ford Foundation and the World Bank have been funding extensively for the conservation and development of medicinal plant ecosystem and biodiversity in India and Asia (Shukla and Gardner 2006).

A report by WHO estimates that more than 80% of the population in both developed and developing countries rely on traditional system of medicines (Batugal et al 2004; Shukla and Gardner 2006), largely plant and herb based therapeutics, to meet their primary health care needs, pharmaceuticals,[21] food supplements, flavouring, perfumes, cosmetic industries, veterinary care etc. Traditionally local use of medicinal plants can be categorized into three categories (i) Traditional System of Medicine (TSM) (ii) Traditional Medicinal Knowledge or Folk Medicine and (iii) Shamanistic or Spiritual Medicine with strong religious and spiritual element which practiced by 'Shamans' (Planning Commission 2000; Hegde 2003; Shukla and Gardner 2006). In addition, women's role in traditional medicinal skills and passing the knowledge to future generation cannot be overlooked (Belt et al. 2003). A majority of 70,000 species used in folk medicine are found in Asia-Pacific region (Batugal et al 2004). While in China, over 5000 plant species are used in various forms of drugs and traditional medicine, here in India over 2500 species[22] are known for its traditional medicinal value (Hegde n.d) and use only 960 varieties of medicinal species out of which 90% is collected from wild. Nearly 43% of the India's rich medicinal biodiversity[23] is situated in Northeastern region (Majeed 2015).

In 21st Century, traditional medicinal practices serve only as alternative therapy[24] due to easy accessibility and lower prices in rural areas. Both traditional and modern system of medicine across the world depends on around 50,000 species (SMPB 2012). As per WHO estimates 60% of India's population depends upon traditional

[20]Refer UNDP's 'Conserving Medicinal Plants, Sustaining Livelihoods' Accesses from (http://www.in.undp.org/content/india/en/home/ourwork/environmentandenergy/successstories/conserving-medicinal-plants-sustaining-livelihoods.html).

[21]For instance 10 out of the world leading 25 top-selling drugs are derived from natural sources in 1997. Similarly, it is estimated that annually the global market value of Pharmaceuticals derived from genetic resources to be US$ 75,000–150,000 million. In India, 226 medicinal plants species are used by the Pharmaceutical Industries (Rao and Arora 2004).

[22]Nearly 359 medicinal species used in Ayurveda fall under endangered category (Majeed 2015).

[23]Rich medicinal plant biodiversity includes (i) Himachal Pradesh (Himalayas) producing and supplying 80% of Ayurvedic medicines, Western Ghats one of the mega-biodiversity of 'hotspots', tropical forest of Vindhyas, Chhotanagpur plateau and Aravalis (Subrat 2002).

[24]There are about 4,60,000 registered practitioners using medicinal plants and 851 homeopathy treatment centres (Planning Commission 2000).

medicines[25] for sustenance and healthcare needs.[26] As per the WHO estimate, 21, 000 plants are reported with medicinal usage around the world (WHO 2002; Shukla and Gardner 2006). According to the estimates, medicinal plant sector provides over one million employment opportunities for local communities like traditional healers, Vaidyas[27] etc. particularly in rural India (ibid). Besides, as 90% of the collection of medicinal plants is from wild, generates about 40 million man-days employment (both part-time and fulltime) (Planning Commission 2000). The fact that medicinal plants are in great demand for allopathic and herbal medicine industries as well as for phyto-medicine (Lewington 1993).

2 Medicinal Plant Cultivation and Economic Viability in India

Numerous studies have documented on the cultivation, conservation and constraints faced in harnessing medicinal plants in India. But only few studies have in fact shows the successful cases of medicinal plants cultivation and economic viability for India farmers. Less than 20 medicinal plant species out of more than 400 major plant species are used for the production of medicine by the Indian herbal industry (CUTS 2004). In India unfortunately, only 36 species are under commercial cultivation (Ved and Goraya 2008 in Majeed 2015).

One such study is by Biswas (2010) which reveals that cultivation of Aloevera and Drumstick vegetable has proven economically attractive for two farmers in Maharastra. Similarly, the studies by Nautiyal (1996), Silori and Badola (2000) and Belt et al. (2003) reveals that the Bhotiya community from western Himalayas region is richly endowed with culture and medicinal plant biodiversity particularly in the region of Nanda Devi Biosphere Reserve (NDBR) cultivation of medicinal plants generated high economic returns as well as contributed substantially for the conservation and preserve the traditional ethno-medicinal knowledge among the local people. Cultivation of medicinal and aromatic plants in Mandakini Valley and Roopkund Valley (Uttaranchal[28] Himalayan[29] region) could generate immense economic opportunities for the local people instead of relying on the secondary sources such as animal husbandry and agriculture practices for few months (Nautiyal et al. 2005). Similarly,

[25]In India, there are over 8000 licensed Ayurveda pharmacies out of which 30% are located in the state of Uttarpradesh alone (Subrat 2002).

[26]Refer UNDP's work on 'Conserving Medicinal Plants, Sustaining Livelihoods' Accessed from (http://www.in.undp.org/content/india/en/home/ourwork/environmentandenergy/successstories/conserving-medicinal-plants-sustaining-livelihoods.html).

[27]For medicinal purpose oral traditions of villagers use about 5000 plants and 8000 species by tribal's and traditional healers (Planning Commission 2000).

[28]In Uttaranchal alone about 701 species are used as medicines (Dhar et al. 2000).

[29]Bhotia, Rajees, Tharus and Boxas are the tribal community live in the state of Uttaranchal (Dhar et al. 2000).

Table 1 Medicinal plants in demand

AONLA	CHANDAN	KALMEGH	SATAVARI
ASWAHAGANDHA	CHIRATA	KATKI	SHANKAPUSHPI
ASHOKA	GILOE	KOKUM	SAFED MUSLI
ATIS	GUGGAL	KERTH	SENNA
BAIBERANG	INDIAN BARBERY	LIQORICE	
BAEL	ISABGOL	LONG PEPPER	
BRAHMI	JATAMANSI	MADHUNASHINI	

Source http://www.indiahomeclub.com/botanical_garden/medicinal_plants_in_demand.html

Medicinal Plant Board Tripura has identified 266 species out which 12 varieties are suitable for cultivation and income generation (Bhattacharjee 2015).

The study by Mishra and Kotwal (2011) clearly documents factors responsible for success and failure in growing, processing marketing medicinal plants in Malwa region of Central India. The study observes that though medicinal crop has increased manifold yet there is scarcity of planting material, marketing and proper management of the planted species, thus, rapidly reducing the Musli area under cultivation. Table 1 depicts the names of medicinal plant species which are in demand in India.

2.1 Objectives of the Study

Following are the main objectives of the study:

1. To assess the current status of Medicinal Plants cultivation in India.
2. To explore the opportunities and constraints in Medicinal Plant cultivation in India.
3. To suggest a framework for harnessing medicinal plant cultivation for promoting food security in India.

2.2 Methodology

Value chain analysis approach[30] has been used to study the scenario of medicinal plant cultivation and its linkages with food security in India. Such analytical approach helps to dissect the linkages between current status, its potential and diverse actors involved in the chain. The framework assists to plan and develop interventions to deal with specific constraints and realise opportunities, and to improve the overall performance

[30]Some of the ideas for Value Chain analysis approach has been inspired by the study of Belt et al. (2003).

in the chain. The value chain approach provides practically implementable models to attain set objectives, besides, plan action for development of medicinal plant sector. Some of the key questions explored are what is the present status of medicinal plant sector in India? Who are the stakeholders involved? What is the economic potential of the sector? What is the present institutional arrangement of the sector? How could you constitute effective linkages between cultivation of medicinal plants and food security in India in the chain?

The study is based on both secondary and primary data sources. For secondary data various documents, reports, journals and books are accessed. In addition, two cases on the traditional use, conservation and economic potential of medicinal plants in the Nanda Devi Biosphere, in the central Himalayan region of India and BRTTR region in Karnataka, is presented.

The study aims to present analysis on quantity of collection and cultivation of medicinal plants, and their economic and commercial potential. The study further presents analytical model for harnessing medicinal plant cultivation for promoting livelihood and food security. This article addresses the cultivation of medicinal plants and economic viability, constraints in the cultivation of medicinal plants and economic potential medicinal plants in India. This paper also documents institutions and agencies involved in development and promotion of medicinal plants in India. Further, the study analyses resource base, utilisation and conservation of medicinal plants across India. At the end the article presents analytical model for harnessing medicinal plant cultivation for improved food security in India.

3 Definition of Medicinal Plants

Medicinal plants have been defined variously by different agencies:

The World Health Organization (WHO 2000:1, 2002) uses the umbrella term 'traditional medicine' and defines them 'as the sum total of the knowledge, skills and practices based on the theories, beliefs and experiences indigenous to different cultures, whether explicable or not, used in the maintenance of health, as well as in the prevention, diagnosis, improvement or treatment of physical and mental illnesses'.

WHO (2003) defines Medicinal plants as 'a plant (wild or cultivated) used for medicinal purpose. Similarly, WHO (2003) defines Herbs as 'Herbs include crude plant material such as leaves, flowers, fruit, seed, stems, wood, bark, roots, rhizomes or other plant parts, which may be entire, fragmented or powdered'. A series of technical guidelines on quality control of herbal medicines are prepared by WHO providing a detailed description of the techniques and measures for appropriate cultivation and collection of medicinal plants as well as record and document necessary data and information during their processing (WHO 2003).

4 Institutions/Agencies Involved in Development and Promotion of Medicinal Plants in India

The government of India constituted National Medicinal Plants Board (NMPB) was constituted in November 2000 under the Chairpersonship of Union Health and Family Welfare Minister to promote and coordinate related to medicinal plants and effectively support policies and programmes for the growth of trade, export, conservation and cultivation. The board is located in the Department of Ayurveda, Yoga & Naturopathy, Unani, Siddha and Homeopathy (AYUSH) of the Ministry of Health & Family Welfare. Under new BJP regime in India, Government of India has allocated Rs. 50,000 million for the growth and development of Dept of Ayush. An Independent National Ayush Mission has been launched for promoting capacity building in the sector. Further, a new portfolio of AYUSH (Ayurveda, Yoga and Naturopathy, Unani Sidha and Homoeopathy) has been created for its development (DNA 2015). The approved outlay for the Dept of AYUSH has been increased from Rs 7750 million in 10th FYP to Rs. 39,880 million in the 11th FYP (GoI 2011).

Particularly, North-eastern region is endowed with rich medicinal plant biodiversity. Keeping this in view, a Resource Centre for AYUSH including medicinal plants in North East has been set up to work as an interface between the State Government and the Department of AYUSH, Ministry of Health and Family Welfare. Further, at the sub-state level (district, block or Taluka and at village levels) programme based interventions related to medicinal plants is organised by local NGOs and community groups (Shukla and Gardner 2006). Two NGOs are contributing yeoman service towards conservation and development of traditional knowledge system they are namely (i) Foundation for Revitalization of Local Health Traditions (FRLHT)[31] and (ii) Rural Commune's Medicinal Plant Conservation Centre (RCMPCC), is based in Pune in the western state of Maharashtra (Table 2).

5 Resource Base, Utilisation and Conservation of Medicinal Plants Across India (Demand and Supply)

Most of the medicinal plants are distributed across diverse habitats and landscape. At present, growth medicinal plants are concentrated in very few states prominently being Jammu & Kashmir, New Delhi, Andhra Pradesh, Gujarat & Daman, few places in Haryana, Himachal[32] Pradesh, Jharkand, Karnataka,[33] Kerala, Madhya Pradesh,

[31] Please visit the link for more information: http://envis.frlht.org/.

[32] Himachal Pradesh with a geographical area of 55,673 km^2 (about 1.7% of the country's geographical area) is richly endowed with more than 3500 species of medicinal and aromatic plants out which 800 species are used within and outside the state (DMAPR 2011).

[33] As per the inventory of medicinal plant database created by FRLHT, Bangalore, the state of Karnataka is endowed with 1838 varieties of medicinal plant species particularly in Western and Easternghats. Similarly, in Tamilnadu-1840, Kerala-2052, Chattisgarh-more than 2000, Orissa-more

Table 2 Ongoing schemes and programmes for the protection and conservation of medicinal plants in India

Schemes and programmes	Activities
12th Five Year Plan (2012–2017)	– Special Purpose Vehicle having common facility centres for manufacture and testing of AYUSH medicines are being set up in eight States – Development of Tertiary Care AYUSH Facilities in PPP mode
Central Sector Scheme for Conservation, Development and Sustainable Management-11 Five Year Plan (2007–2012) outlay	– Allocation of 321.30 crores – thrust is provided to in situ and ex situ conservation of medicinal plants – A network of more than 360 herbal gardens have been established across the country, as part of Ex situ conservation efforts
Central Scheme-National Mission on Medicinal Plants (2008–09)	– Approved with a total outlay of Rs. 6300 million for the implementation during 11th Plan – Subsidy is provided for farmer for the cultivation of medicinal plants with backward and forward linkages. So far 1.8 lakh hectares of farmer land has been covered
National Parks and Sanctuaries	– There are 87 National Parks and 447 Wildlife Sanctuaries – Wildlife Sanctuaries extending over an area of about 1.5 lakh square kilometer and National Parks stretch over 34,819 km^2 in India – 8th Five Year Plan (1989–1997) allocation of Rs. 495 million – 9 th Five Year Plan (1997–2002) outlay—Rs. 1100 million
All India Coordinated Research Project of Ethnobiology (AICRPE)—Man and Biosphere	The study has covered about 80% of the tribal areas
National Afforestation and Eco-development Board (NAEB)	Conservation or restoration of sacred groves
Minor Forest Produce was started in 1988–89 (Seventh Plan)	Cultivation of medicinal plants like Rauwolfia spp, Dioscorea spp to augment the rising demand for plant-based drugs and to offfest the scarcity because of unscientific exploitation

(continued)

Table 2 (continued)

Schemes and programmes	Activities
Ninth Five Year Plan (1997–2002), the scheme is being operated in 25 States	– Financial allocation of Rs. 80.5 million – Conservation and improvement of the non-timber forest produce, including medicinal plants – Increasing the production of and replenishing the stock of non-timber forest produce and medicinal plants
Sub-programme on “Medicinal Plants Conservation and Sustainable Utilisation”—UNDP (1999)	– The activities include survey and inventorisation of medicinal plants in the selected areas in the State of Andhra Pradesh and Maharashtra – Setting up of 8 Medicinal Plants Conservation Areas (MPCAs) in each of these states. These areas are demarcated as “no harvest zones”
Foundation for Revitalization of Local Health Traditions (FRLHT), Bangalore (NGO)	– In situ conservation areas have been marked
Global Environmental Facility (GEF) Small Grants Programme	– The United Nations Development Programme (UNDP) operates the Small Grants Programme on behalf of Global Environmental Facility (GEF) – Twenty Four projects were approved in 1995 and 1997 (20 on Biodiversity and 4 on Climate Change covering 12 States)
Botanical Survey of India (BSI)	– Responsible for inventorisation of plant resources and compilation of the flora of India
Indian Council of Forest Research (ICFRE)	– Collection of germplasm of the 25 plant species identified by the Task Force for cultivation – To make available high quality planting material by developing a network on nursery of medicinal plants – Human-resource development by organising training programmes on agropractices, post-harvest technology and quality control techniques
Wild Life Wing of Forest Department	– Establishment of 200 Medicinal Plant Conservation Area (MPCA)
State Forest Departments	– Identify forest areas rich in medicinal plants for intense management – Establishment of 200 “Vanaspati Van” in degraded forest areas

Source Planning Commission (2000, 2013) and other sources

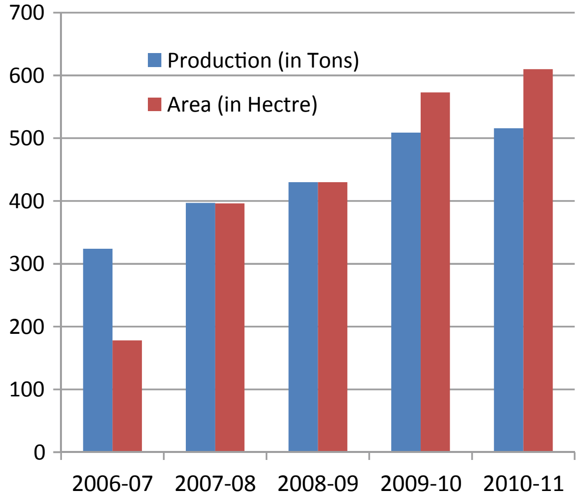


Fig. 1 Production and area covered by medicinal and aromatic plants in India (across years). *Source* GoI (2013)

Maharastra, Mehalaya, Orissa, Punjab and Chandigarh, Rajasthan, Pondicherry, Tamilnadu, Uttarpradesh and Uttaranchal. Majority of medicinal plant growers are from Kerala and Maharastra.[34] Besides, Western and Easternghats, the Vindhyas, Chotta Nagpur plateau, Aravalis and Himalayas produce 70% of India's medicinal plants. While less than 30% of medicinal plants are found in the temperate and alpine areas (Planning Commission 2000; Bera 2010; Kala 2006; Directorate of Medicinal and Aromatic Plants Research 2011).

Cultivation and area of aromatic crops has been steadily increasing from the year 2006–07 to 2010–11 (GoI 2013) (see Fig. 1). Yet over the years, actual cultivation does not commensurate with the increase in area of cultivation.

6 Conservation Efforts

Meanwhile, recently NMPB has undertaken to implement centrally sponsored scheme (during 11th Plan) in support of market driven strategies promoting medicinal plant cultivation on private land across identified zones/clusters within selected districts of states. The scheme aims to promote 'Conservation, Development and Sustainability Management' of medicinal plants for overall development, cultivation, resource augmentation, sustainable collection, research, processing and marketing. So far, under the scheme following activities are done to promote and develop medicinal plants in India they include (i) 636 nurseries of medicinal plants have been set up

than 1500, Rajasthan-more than 500, West Bengal-2800, Sikkim-1681, Available at (http://envis.frlht.org/checklist/karna.pdf).

[34]List of growers from National Medicinal Plants Board (NMPB).

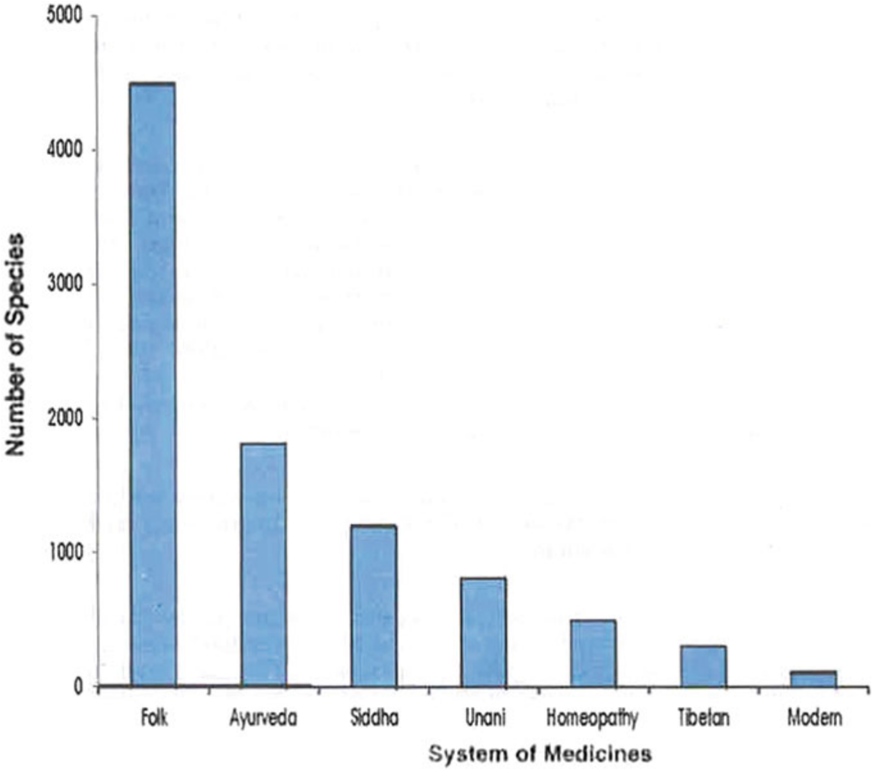


Fig. 2 Plants Used by various system of medicines in India. *Source* Planning Commission (2000)

(ii) coverage of 51,308 ha of land for the cultivation of medicinal plants (iii) 25 post-harvest infrastructure units are supported and (iv) 5 processing units and 2 market promotion units are set up (Planning Commission 2011). The Institute of Biodiversity Conservation (IBC) has initiated the development of a project on Conservation and Sustainable Use of Medicinal Plants (CSMPP) (Kasagana and Karumuri 2011) (Fig. 2).

7 Constraints in the Cultivation of Medicinal Plants

At present, cultivation of medicinal plants is completely scattered and unprioritised for various reasons. Only 20% of the 178 major medicinal plant species are traded as raw drugs (Planning Commission 2013). In India less than 10% of medicinal plant species are cultivated and 90% are collected from wild (Uniyal 2015). For most part, cultivation is done as nurseries or as secondary income among the tribal communities of Himalaya region particularly in Uttaranchal (Dhar et al. 2002; Nautiyal et al.

2005) without forward linkages for post-harvesting management, processing or marketing infrastructure. For instance, though North-eastern[35] region[36] is endowed with rich medicinal biodiversity in flora, vegetation, culture and climate yet medicinal plant cultivation is restricted to traditional application and most often the produce is undervalued for poor quality. Lack awareness on harnessing for sustainable use and market needs adds to the constraints (Haridasan 2015). Many medicinal plant species are under threat[37] due over exploitation for modern industries. According to the studies, about 112 species in Southern India, 74 species in Northern and Central India and 42 species in the high altitude of Himalayas are seriously threatened in the wild (Uniyal 2015). Table 3 provides a glimpse on various types of constraints for harnessing medicinal plant cultivation in India.

Unsustainable use of medicinal plants and herbs for Pharmaceutical, Aromatic-chemical industries is causing fast depletion from its natural habitats (Nautiyal et al. 2005). As per the International Union for Conservation of Nature and Natural Resources (IUCN) 16 Red List of Threatened Species, more than 300 plant species which includes medicinal plants are threatened with extinction (CUTS 2004). Globally only very few medicinal plant species are cultivated on large and those cultivated does not cater to the global demand. For instance in China, only 100–250 species of medicinal plants are cultivated on large scale. Even in Europe, out of the 1200–1300 species of native medicinal plants only 130–140 are derived predominantly from cultivation (ibid).

8 Harnessing Medicinal Plant Cultivation for Improved Food Security in India

Harnessing medicinal plant cultivation for improved food security in India is the area which has been largely underexplored. Medicinal plants particularly, herbal plants have been contributing significantly to the livelihood of rural communities particularly the tribes who rely on benefits from traditional medicinal practices for monetary and non-monetary (GoI 2011; Planning Commission 2000) purposes. Medicinal Plant Conservation Areas (MPCAs) are created for conservation of rich biodiversity of medicinal and aromatic plants FRLHT (See footnote 31). The Foundation for Revitalisation of Local Health Traditions (FRLHT)—a Bangalore based NGO has established 34 MPCAs in South India. Besides, MPCAs network has already started in many states of India to supports sustainable use and for expanding the benefits of equal-sharing (Rajpurohit and Jhang 2015). Similarly, efforts are made to cultivate

[35]Eight states forming North-eastern region is richly endowed with flora and fauna. Each state has its own forest coverage which is above national average of 21.05% (Haridasan 2015).

[36]The Northeast region has secured its place as one of the 25 hot spots of mega diversity with rich medicinal plant species and endemism (Majeed 2015).

[37]At least 40 threatened or endangered species constitute Germany's imports (Lambert et al. 1997).

Table 3 Types of constraints for harnessing medicinal plant cultivation in India

Types of constraints	Issues
Institutional (policies and programmes)	– Lack of data sources – Lack of Integrated Policies and Programmes targeting cultivation of medicinal Plants – Lack of Research on Medicinal Plant Cultivation – Lack of resource survey or inventory (region-wise) of rich medicinal biodiversity – Lack of supporting policies and subsidies for cultivation of medicinal plants – Trade barriers – Lack of effective domestic regulations – Lack of effective enforcement environmental regulations – Lack of organised form of administrative and legal forms – Land ceiling acts – Lack of institutional support for folklore and traditional medicines
Economic	– Lack of income among the poor farmers – Lack of better returns on investment – Lack of reasonable price fixation and profitable price levels leads to price fluctuations – Low prices and devaluation of local knowledge by the communities
Social	– Lack of scientific knowledge and awareness on Biodiversity Act and Regulation process – Exploitation, indiscriminate collection in wild and Unsustainable practices [Around 315 of 6560 medicinal species are threatened with extinction (Niraj and Kapoor 2015)] – Lack of sharing the benefit or giving credit on traditional medicinal plants with communities

(continued)

Table 3 (continued)

Types of constraints	Issues
Technical	– Lack of baseline data or knowledge on sustainable cultivation and Harvesting/Post-Harvesting Practices – Lack of consolidation of Sanskrit knowledge scattered around the country – Medicinal plant cultivation and collection is unscientific and over-exploitative – Difficulty in assessment of species extracted from wild – Unscientific harvesting practices – Lack of monitoring or regulation of the extraction and trade of medicinal plants – Lack of scientific development of high yielding varieties of medicinal plants (breeding or clonal micro propagation) – Lack of agro-technology – Lack of Infrastructure for quality testing, processing and marketing – Lack of scientific understanding and monitoring medicinal biodiversity – Lack of trading centres and transport facilities – Lack of regulation and organised form of transactions – Lack of improved technology transfer – Absence of standardisation for exporting medicinal plants – Lack of R&D efforts in the sector – Absence of standard system of certification including verification and quality control – Unclear harvesting procedures, lack of suitable soil conditions, irrigation facilities, preserving quality planting material – Non-uniform transit formalities and tax structure across different states and major wholesale markets – Lack of suitable weather reports – Lack of skill development and technical knowhow – Lack of efficient marketing facilities and absence of credible marketed linkages – Lack of quality and quick deterioration of the products – Lack of storage facilities and procedures, post-harvest management and their training needs – Lack of simple and appropriate agro techniques – Secretive and unorganised nature of medicinal plant business – Lack of transparent supply chain information and mutually enforcing code of collection and sharing of marketing benefits

(continued)

Table 3 (continued)

Types of constraints	Issues
Sustainability	– Rapid urbanisation and Commercialisation of medicinal plant extraction – Decline in the use of traditional knowledge for conservation – Overuse of medicinal plant diversity for pharmaceuticals, aromatic and industrial consumption – Lack of multi-sectoral approach – Lack of holistic development of all land based resources/departments (forest, agriculture, animal husbandry, health, water conservation, mining etc.) – Long gestation period – Non application of organic farming – Lack of sustainable harvesting protocol – Shift from traditional use to commercial use and sale – Small land holdings – Lack of support in wasteland development
Types of measures to promote medicinal plant cultivation	
Sustainable measures	– Capacity Building Training and Workshop for Cultivation and Conservation of Medicinal Plants – Establish linkages with health care & Eco-tourism: Panchakarma experience

Source From various sources

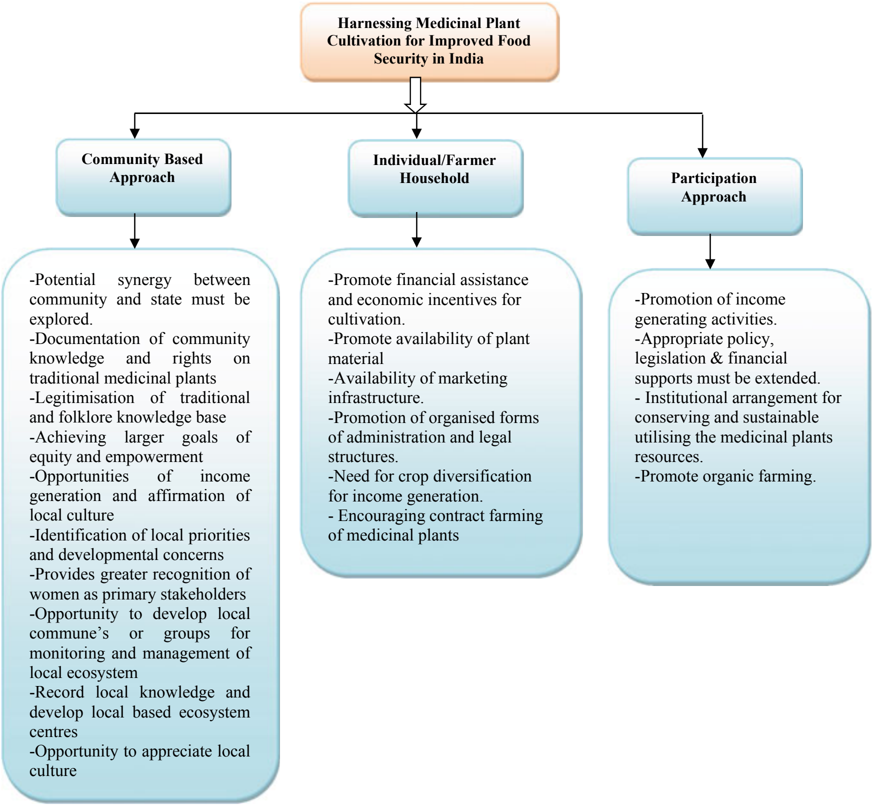
medicinal plan species and agro-based technology for more than 20 species of rare and endangered (Das 2010).

To tap the enormous employment potential of medicinal and aromatic plants in India following recommendations were made by Planning Commission (Planning Commission 2002; Kapila and Kapila 2002):

1. To promote intensive management of medicinal plants, MPDA/Vanaspati Van over an area of 1 million ha was envisaged. Under ‘food for work’ scheme 10 lakh people were expected to get productive employment.
2. As per the Task force on Medicinal Plants, nearly one million could be expected to employed besides 1 lakh were expected to be employed in 10,000 pharmacies, health tourism and in the manufacture of various products. In addition, by the end the 11th FYP, 0.5 million were expected to be employed in Medicinal Plant sector.
3. On recommendation of Task force Report by Planning Commission Report (2000), National Medicinal Plant Board (NMPB) has into existence. Concerted efforts are made to generate 1.1 million jobs annually.

Various studies have recommended models and approaches such as (i) Community based approach/Stakeholders approach (ii) Individual/Farmer based and (iii) Participation approach for linking medical plants and food security. Integration of medicinal plants therefore, into various forms of commercial agriculture cropping systems that could assist in generating employment opportunities and income has been significantly overlooked. Further, the significance of indigenous medicinal plant cultivation for survival especially among rural communities and tribes has not been addressed. Therefore, the correlation between cultivation of medicinal plants for improved food security especially in India cannot be overruled.

8.1 Model for Harnessing Medicinal Plants Cultivation for Improved Food Security in India



Studies enumerate the key role of women in the cultivation and conservation of medicinal plants especially in North-eastern India. For instance in Kmhmu of Lao (North Eastern India) indigenous women play critical role in the cultivation of 50 varieties of medicinal plants. Here women richly contribute in the preservation of seeds, transfer of knowledge and thus play a key role in the preservation of agro-biodiversity of the region (Erni 2015). In many countries, particularly in India, distinction between medicine and food is not clear many medicinal plants obtained from forest are used in their food. Especially in traditional rural societies, wild or domesticated medicinal plants constitute main source of income and, besides, medicinal plants offer treatments for most common ailments and improve nutritional status (FAO n.d).

Forest communities especially in Manipur region consider medicinal plants as sacred plants having healing capacity for treating common ailments (Phurailatpami et al., n.d; Harisha et al. 2016).

9 Economic Potential of Medicinal Plants Contributing to Household Income

As India is endowed with medicinal plants, they are used by both rural and urban communities as diet supplements, medicine and alternative source of cash income. Studies reveal that cultivable area of medicinal plants like—amla, ashwagandha, sarpagandha and bio-fuel crops like jatropha has drastically increased in recent years (Brahmanand et al. 2013).

AYUSH (Ayurveda, Yoga & Naturopathy, Unani, Siddha and Homeopathy) is estimated to contribute an estimated Rs. 80–90 billion per year (Alok 1991; Hegde 2003; Nautiyal et al. 2015). Harnessing medicinal plants provides great source of income to rural population particularly the tribal belt in Himalayan region and affirmation of local traditional practices. Moreover, demand for medicinal and aromatic species have grown multitude due to international pharmaceutical market (Kumar 2002; Hegde 2003; Belt et al. 2003). It is estimated that 4635 ethnic communities in India are treating human and veterinary disorders by practicing either Ayurveda, Siddha, Unani and late Tibetian system of treatment (Hegde 2003).

According to an estimate, nearly 50 million people rely on non-timber forest produce (NTFP) and majority of the produce being medicinal plants. Studies point out that collection and processing of medicinal plants contribute to at least 35 million workdays of employment annually. It is confirmed that cultivation of medicinal plants is more profitable[38] than cash crops (Uniyal et al. 2002; Belt et al. 2003; CUTS 2004; Bera 2011).

For instance, around the Great Himalayan National Park in Kulu valley, for majority of the people medicinal plant collection and sale contributes an average income of Rs. 10,000 per family in 1997 (CUTS 2004). But unfortunately, nearly 70% of the medicinal plant cultivation in Himalayan region is destructively harvested[39] (Planning Commission 2000; Banerji and Basu 2011). Most of the natural habitats are fast disappearing for industrial and commercial activities generating substantial negative environmental impacts. On the other hand, ban on collection and illegal trade have put stress on income generation (Belt et al. 2003). In Devarayanadurga forest, Western Ghats, 167 medicinal plants are locally used (Ramakrishappa n.d).

Global market for medicinal and aromatic plants have increased manifold. By 1980s the WHO assessed the world trade of medicinal plants to $500 million a year (Lambert et al. 1997). But diverse studies suggests to the continuous growth of overall medicinal and aromatic plants across the globe (both in terms of cultivation and trade).

As per the Secretariat of the Convention on Biological Diversity, global sales of herbal products totalled an estimated US$ 60,000 million in 2000 (WHO 2003).

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[38]For instance, cultivation of kuth (Sassurea costus) and Sarpagandha (Rauwolfia servpentina) fetched between Rs. 14,000 and Rs. 45,000 per hectare respectively. And farmers are expected to earn Rs. 31,000 per hectre (CUTS 2004).

[39]For instance, less than 20 out of estimated 800 species are commercially cultivated discouraging due to long gestation period (Banerji and Basu 2011).

According to the World Health Organisation (WHO) estimate, the demand for medicinal plants is approximately US$ 14 billion per year (Majeed 2015). Between 1992–93, India exported about 32,600 tonnes of crude drugs valued at $US 46 million (Dhar et al. 2002). As the demand for medicinal plants is rapidly increasing worldwide, economic potential of medicinal plants in India[40] is growing leaps. By 2002, domestic sales was growing at the annual rate of 20% while the international market for medicinal plants was estimated to be growing by 7% per annum (Subrat 2002; CUTS 2004). International market[41] for medicinal plants is over US$ 62 billion[42] per year, which is growing rapidly at the rate of 7%. By 2000, India was exporting herbal material and medicine to the tune of Rs. 6446.3 million. The global herbal market amounts to US$ 120 billion and is expected to grow to Rs. 250 billion by 2010 (Planning Commission 2000) and US$ 5 trillion by 2050 (Singh 2006; Niraj and Kapoor 2015). According to the report by EXIM Bank of India's, the estimated value of medicinal plants related trade in India is worth $ 5.5 billion (Planning Commission 2000; Mishra and Kotwal 2011) just 0.5%.

Numerous studies documented varied estimates of export and import of medicinal plants of India. According to the study by Kumar and Janagam (2011) India's average export of Medicinal plants was Rs. 33,453.23 lakhs during 1991–92 to 2002–2003. Its overall trend showed an increase of 0.21%. And the average Import was Rs. 2827.01 lakhs. Overall trend has been an increase of 0.39% from India. Another study shows that the export of Ayurveda, Homeophathy and Siddha stood US$ 348 million and showing a growth of 16.5% (Niraj and Kapoor 2015). While one estimate the annual turnover of the Indian[43] herbal medicinal industry is about Rs. 75,000 million contributing a growth rate of more than 15%. Another study by the Associated Chamber of Commerce and Industry (ASSOCHAM), the Indian herbal industry has projected to double to Rs. 15,000 million by 2015, from the current 75,000 million business.[44] The apex chamber estimated that global herbal industry is expected to grow to Rs. 700,000 million by 2015, more than double from the current level of Rs. 300,000 million. Small-scale players in the sector are likely to contribute substantially in the future. Such differential estimates are due to enormity and complex medicinal plant system in India[45] (Subrat 2002). In addition, illegal trade and unaccounted species contribute substantially for industries like flouring, perfumes and tenderising

[40]There are about 6 major, 21 medium and 37 minor medicinal plant markets spread across India. Major exports takes place in New Delhi, Mumbai, Chennai and Tuticorin. There are about 25 companies in private sector engaged in nursery, generation, development of agricultural techniques and farmers to cultivate medicinal plants (Subrat 2002).

[41]Germany is the largest importer of medicinal plants (Lambert et al. 1997).

[42]Access the link for more details (http://www.agricultureinformation.com/forums/general-questions-answers/34618-cultivation-medicinal-plants-india-government-support.html).

[43]Major players in Indian Ayurveda industry include Dabur, Baidyanath, Himalaya Drugs and Zandu Pharmaceuticals, Ajanta Pharmaceuticals.

[44]Access the link for more details (http://www.niir.org/projects/projects/highly-demandable-herbs-medicinal-plants/z,,2b,0,64/index.html).

[45]Studies point out that huge volume of illegal medicinal trade does account the total volume of export (Subrat 2002).

etc. (Belt et al. 2003). It is also observed that, out of 960 traded medicinal species, 178 are consumed in volumes exceeding 100 MT per year. The consumption accounts for 80% of the total industrial demand (Ved and Goraya 2008; Nautiyal et al. 2015).

Some of the major suppliers to the world market are china, Singapore, Brazil, India and Egypt. The leading trade centres are United States (US) and the European Union (EU) and Germany (Belt et al. 2003). The global trade of medicinal plants amounts to US$7,592 million by 2011 with the share of China is US$1,329 million and India US$790 million (Majeed 2015). So both China and India two largest producers of medicinal plants have more than 40% share of global biodiversity. While China is the largest exporter (1,21,900 tonnes a year) of medicinal plants followed by India (32, 600 tonnes a year) (CUTS 2004; Rao and Arora 2004). China exports based on plants are estimated to be around Rs. 180,000 to Rs. 220,000 million (ibid). Estimated domestic trade of AYUSH industry is Rs. 80 to Rs. 90 billion and accounts Rs. 10 billion for exports alone. But Indian share of world medicinal trade very quite low as compared to world herbal trade constituting US$ 120 billion which is expected to reach US$ 7 trillion by 2050.[46] For the year 2004–05, India exported 40,000 metric tonnes of medicines in raw form.[47] During 11th Plan year only 20% of the 178 major medicinal plant species were traded as raw drugs (Planning Commission 2013). At International level demand for medicinal plants is very strong in US, Europe, Japan and South East Asia with sizeable markets. Countries like USA, Germany, UK, France and China/Taiwan are major importers of Indian medicinal plants, together accounting for 75 per cent of total exports (Subrat 2002).

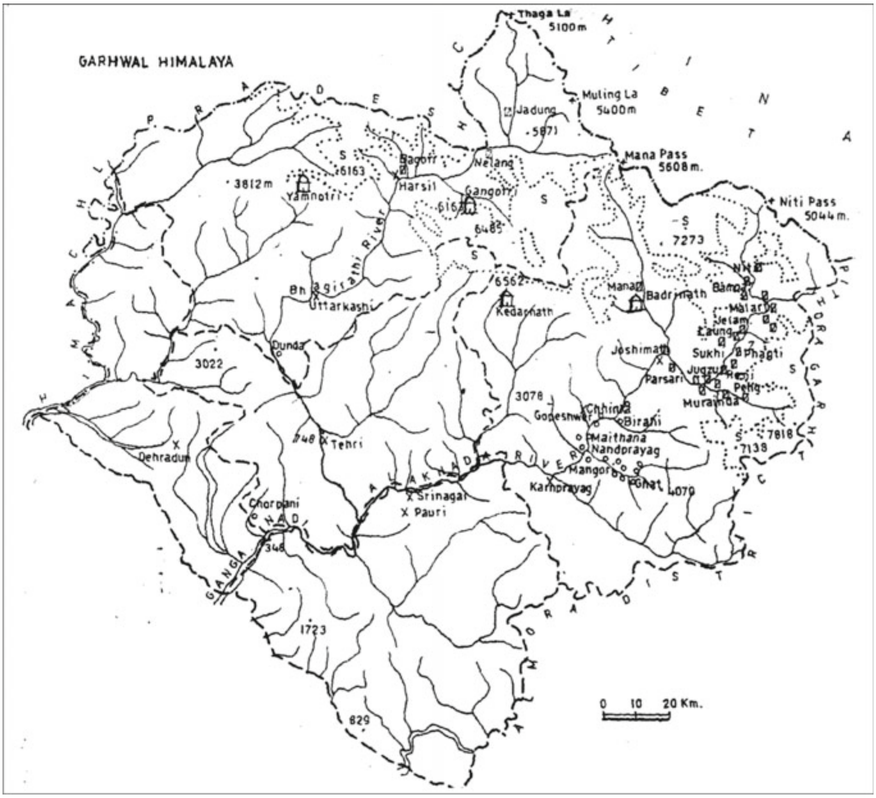
9.1 Case Studies on the Role of Indigenous Communities in the Conservation of Medicinal Plants and Food Security

Here two cases on the traditional use, conservation and economic potential of medicinal plants in the Nanda Devi Biosphere, in the central Himalayan region of India and BRTTR region in Karnataka, is presented.

Out of 2500 medicinal plant species in the Indian sub-continent region, majority of medicinal plants are grown in Himalayan region. Especially, indigenous Bhotiya communities greatly rely on medicinal plants for their livelihood. The settlement of Bhotiya community (see Picture 1) is located on the upper Rishi Ganga catchment area in the Nanda Devi Biosphere reserve, of Uttarakhand state (Chamoli district). A total of ten villages consisting of 2253 population (419 households) belong to an Indo-Mongoloid ethnic group. This Bhotiya community has three sub-communities namely: Tolchha, Marchha and Jadh. Among these sub-communities, a total of

[46]From National Medicinal Plant Board (NMPB). Refer (http://nmpb.nic.in/).

[47]National Medicinal Plant Board (NMPB) (2012). Centrally Sponsored Scheme of National Mission on Medicinal Plants: Operational Guidelines. Access from: (nmpb.nic.in/…/7848115600Proposed%20Centrally%20Sponsored%20Sc).



Bhotiya's summer dwelling , o Bhotiya's winter dwelling, x Other areas Snow covered areas

Picture 1 Dwelling of Bhotiya communities of Central Himalaya, Uttarakhand. *Source* Nautiyal et al. 2001

13.7 ha land (0.4% of the total land) belonging to only Tolchha and Marchha is cultivating medicinal plants (see Table 4).

A variety of forest produce (kg/capita/year dry wt basis) collected from different purposes by the three sub-communities of Bhotiya tribe of the Central Himalaya is presented below (see Table 5). Medicinal plants of 100 varieties are used by the communities and out of these plants, 97 species are used for curing various types of ailments such as: common cold, muscular & rheumatic pain, head-aches, gastric/liver disorders etc. and 16 varieties of species are stored for family use. To cure various ailments, majority of population belonging to all sub-communities of Bhotiya tribe still depend on herbal medicine (see Fig. 3) and less number of people prefer allopathic treament.

Bhotiya communities generate income from natural resources including by selling medicinal plants is presented below (see Table 6).

Table 4 Socio-economic profile of Bhotiya Communities, Central Himalaya

Socio-economic Profile	Bhotiya sub-communities		
	Tolchha	Marchha	Jadh
Number of villages	20	5	1
Number of households	634	364	223
Total population	3677	2220	1382
Male	1154	805	460
Female	1267	838	480
Children below 15 years of age	1256	577	442
Sex ratio	1097	1040	1043
Total literacy (%)	36	46	53
Household size	5.8	6.0	6.2
Land under agriculture (ha)	640	250	26.05
Land under medicinal plants cultivation (ha)	11.4	2.3	–
Per capita average land holding (ha)	0.17	0.11	0.019
Total livestock	11,272	5080	36,381
Per capita average livestock	3.06	2.28	26.3
Main occupation	Agriculture	Agriculture	Animal husbandry
Subsidiary occupation	Animal husbandry	Animal husbandry	Agriculture

Source Nautiyal et al. (2001)

Usually, Bhotiya communities collect medicinal plants from the wild as subsidiary occupation. But the community had to relinquish their traditional rights on collection of medicinal plants on the formation of National Park or Biosphere Reserve in India. During the study, it has been found that income from the collected medicinal plants was higher than the income from other cultivated products. Traditional occupation of collection of medicinal plants and income generation is hit by the exploitation by market forces and land resource ownership system framework initiated due to the formation of National Park/Biosphere Reserve. Such delimitation imposed by the Biosphere reserve restricts the utilisation of wild resources for income generation which is important for the food security. Further the local communities are unaware of the full potential of medicinal plants particularly in terms of product value and marketing. Bartering the traditional system of exchange in the Himalayan region, is fast disappearing with the increase of diversification among the Bhotiya communities.

Case Study 2: Soliga tribal community of BRTTR, India

Soliga tribal community resides in BRTTR of Yellandur and Kollegal Taluks, Chamarajanagar district, Karnataka covering an area of about 540 sq. km. (Fig. 4). More than 300 varieties of medicinal plants are found in BRTTR region.

Table 5 Forest produce of Bhotiya Tribe of Central Himalayan region

Scientific name	Local name	Bhotiya sub-communities									
		Tolchhas			Marchhas			Jadhs			Mean
		1	2	%	1	2	%	1	2	%	%
Vegetables											
Allium semonovii	Doom	4.8	121	65	3.2	80	58	–	–	–	41
Chenopodium foliolosum	Bethuwa	0.36	1.45	25	1.5	5.5	48	2.1	10.1	53	42
Diplozium esculentum	Lingura	1.3	13.0	65	5.6	56.0	70	4.00	40.0	74	70
Fagopyrum dibotrys	Dyokai	0.43	0.90	20	1.7	3.74	65	1.6	3.52	50	45
Megarcapaea polyandra	Barmao	2.5	15.0	80	8.5	51.0	100	3.0	18.0	63	81
Morchella esculenta	Guchhi	0.28	396	100	0.33	594	100	0.43	774.0	100	100
Paeonia emodi	Chandra	2.2	13.2	56	4.0	24.0	63	–	–	–	41
Phytolacca acinosa	Jagra	0.15	0.90	45	0.60	3.6	50	–	–	–	32
Rumex hastatus	Jangli palak	0.36	2.20	40	–	–	–	0.72	4.40	48	30
Smilacena purpurea	Puyanu	3.0	15.0	48	2.5	12.5	40	–	–	–	30
Total		15.38	579		28.0	831		11.8	831		
Wild fruit											
Hippophae rhamnoides	Amesh	0.50	8.00	37	1.5	24.0	62	0.07	0.75	20	40
Juglans regia	Akhor	2.7	67.5	82	1.35	34.0	55	–	–	–	45
Ribes himalayense	Darbag	0.60	6.00	42	0.52	5.20	41	–	–	–	27

(continued)

Table 5 (continued)

Scientific name	Local name	Bhotiya sub-communities									
		Tolchhas			Marchhas			Jadhs			Mean
		1	2	%	1	2	%	1	2	%	%
Rosa marophylla	Sedum	0.30	1.80	45	1.70	10.0	65	0.50	3.00	36	48
Viburnum cotinifolium	Kathya	2.80	22.4	70	1.20	9.60	35	–	–	–	35
Total		7.0	105		6.27	82.8		1.2	3.75		
Traditional tea											
Taxus baccata	Thuner	2.45	73.5	100	0.15	4.5	65	–	–	–	55
Bergenia ligulata	Silphori	0.82	65.6	18	1.4	112.0	82	0.3	24.0	12	40
Betula utilis	Bhoj patra	0.2	8.0	20	–	–		–	–	–	6
Total		3.47	147		1.55	116.5		0.3	24.0		
Edible oil											
Prinsepia utilis	Bhaikula	5.00	84.0	22	9.0	151.2	42	–	–	–	32
Prunus armeniaca	Chulu	3.00	60.0	80	2.0	40.0	65	1.0	20.0	30	58
Prunus persica	Kirol	2.10	48.0	46	1.0	22.0	20	–	–	–	33
Total		10.1	192		12	213		1.0	20.0		
Medicinal and aromatic plants											
Aconitum heterophyllum	Metha	0.03	2.4	78	0.08	7.2	80	0.09	8.0	80	79

(continued)

Table 5 (continued)

Scientific name	Local name	Bhotiya sub-communities									
		Tolchhas			Marchhas			Jadhs			Mean
		1	2	%	1	2	%	1	2	%	%
Allium humile	Pharan	1.5	90.0	100	0.8	48.0	90	0.17	15.0	48	79
Angelica glauca	Choru	0.24	4.8	92	0.20	4.5	90	0.8	18.0	95	92
Arnebia benthamii	Balchari	0.42	16.8	30	0.37	14.8	30	–	–	–	20
Cedrus deodara	Deodar	0.06	3.6	66	0.04	2.40	60	3.75	168.0	100	75
Dactylorhiza hatageria	Hathazari	0.01	4.7	90	0.01	4.7	90	0.27	35.0	86	88
Nardostachys grandiflora	Jatamashi	0.35	30.0	76	0.47	40.0	80	0.77	60.0	85	80
Picrorhiza kurrooa	Karuwi	0.30	18.0	96	0.18	10.8	78	0.52	34.0	79	84
Pleurospermum angelicoides	Chippi	0.35	8.0	92	0.30	8.0	88	0.12	3.0	73	84
Rheum australe	Archa	0.28	16.8	59	0.20	16.0	42	–	–	–	33
Saussurea costus	Kut	0.15	4.5	96	0.30	9.0	100	1.5	50.0	100	98
Total		3.69	200.0		3.0	165.0		80.0	391		

Source Nautiyal et al. (2001)

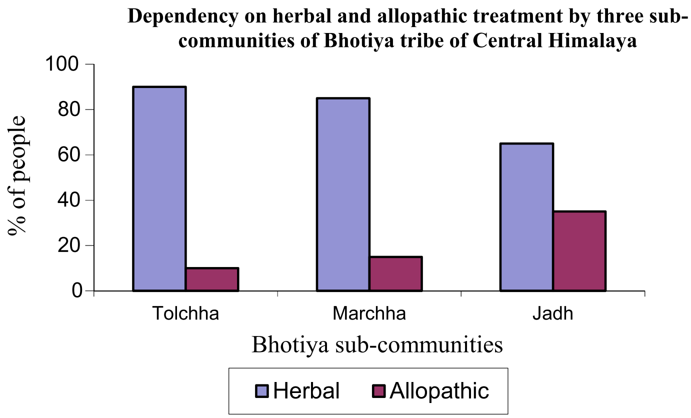


Fig. 3 Dependency of Bhotiya Community on herbal & allopathic treatment

Table 6 Income from natural resource (from selling of MAP) among three Bhotiya sub-communities of Central Himalaya

Categories	Population eligible for collection	Estimated no. of collector	% of house-hold collecting	% of house-holds less than Rs. 10,000 Annual Income	Average MAP Income per capita per year
Tolchhas	2321	1508	90	65	615
Marchhas	1643	1150	85	70	920
Jadhs	940	705	75	83	850

Source Nautiyal et al. (2001)

The Soligas of BRT[48] (Hills of Biligiri Rangaswamy Temple) continuously interacting with forest and practicing shifting cultivation for centuries (Madegowda and Usha Rao 2014). The Soligas for centuries have practiced ecological knowledge and contributed for the biodiversity conservation. Studies have revealed that out of 118 medicinal plants, 26 plants are culturally significant and 14 plants are economically important (Harisha et al. 2016).

There are 61 Podus[49] or settlements of Soliga community at BRTTR region (see Table 7), with total of 2854 households and 15,954 population (Nautiyal et al. 2016).

[48] A BRT Wildlife Sanctuary area spreads over 574.82 km^2 and is located between 77°–77° 16° E and 11° 47°–12°09° N. The BRT wildlife sanctuary has a diversity of forests from scrub forest, deciduous, moist deciduous forest, semi evergreen, ever green, shola and grass land. The BRT Wildlife Sanctuary is rich in flora and fauna. The BRT Wildlife Sanctuary was declared as a Tiger Reserve in 2011 (Madegowda and Rao 2014).

[49] The tribal community households of BRTTR region are known as 'Podu' in their regional language (Nautiyal et al. 2015).

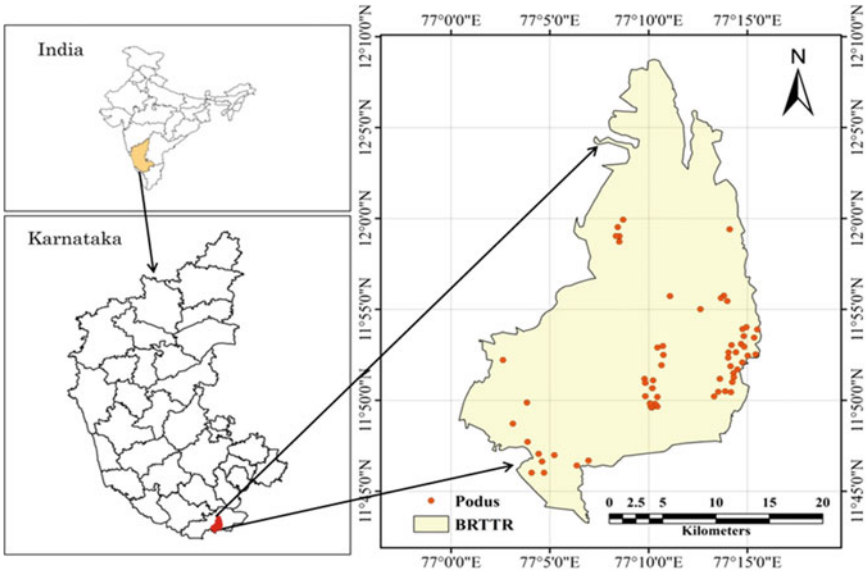


Fig. 4 Location of the study area Biligiriranga Swamy Temple Tiger Reserve (BRTTR). *Source* Nautiyal et al. (2016)

Table 7 General characteristic features of Soliga tribal community, BRTTR, India

Total number of podus (settlements)	61
Total number of households	2854
Total population	15,954
Main occupation	Collection of NTFPs
Subsidiary occupation	Agriculture, Daily wages
Major crops cultivated	Coffee, pepper, finger millet, maize

Source Nautiyal et al. (2016)

Their main occupation is collection of non-timber forest products and agriculture is their main subsidiary occupation. Major crops cultivated include coffee, pepper, finger millet and maize. Further, ecological status of the plant species in BR hills is presented below (see Table 8).

Both Soliga's and non-Soliga communities practice the traditional medicine for curing various ailments. More than 200 species of medicinal plants are used for curing different ailments. Various medicinal plant species are documented for curing various ailments by Soliga tribe at BRTTR presented below (see Table 9; Fig. 5 and 6).

The total produce of medicinal plants though deteriorating under fast pace urbanisation yet generates considerable income for the Soliga community.

Table 8 Ecological status of plant species in BR hills

Ecological status	No of plant species
Vulnerable	9
Endangered	7
Endemic	3
Low risk-least concerned	2
Data deficient	1
Globally distributed	86

Source Nautiyal et al. (2016)

Table 9 Various plant species documented for curing various ailments by Soliga Tribe of BRTTR

Common diseases	No of plant species	Major diseases	No of plant species
Bone fractures, calcium deficiency	3	Anemia	1
Diarrhea	12	Arthritis	8
Gastrointestinal problems	4	Asthma	10
Headache	6	Blood pressure	1
Back and body pains	4	Chest pain	5
Cold, cough	11	Conjunctivitis	1
Eye infections, earache	2	Diabetes	9
Fever	10	Elephantiasis	1
Hair fall, dandruff	6	Jaundice/liver problem	2
Hemorrhage	1	Kidney stones	1
Inflammation, injuries, wounds	13	Mumps	1
Memory power	2	Snake bite, scorpion bite	6
Mouth ulcer	7	Tuberculosis	1
Purification of blood	2	Tumors	2
Reducing body weight	1	Urinary tract infections	2
Rejuvenator/Strength	8		
Skin diseases/pigmentation	19		
Toothache	2		
Weakness	2		

Source Nautiyal et al. (2016)

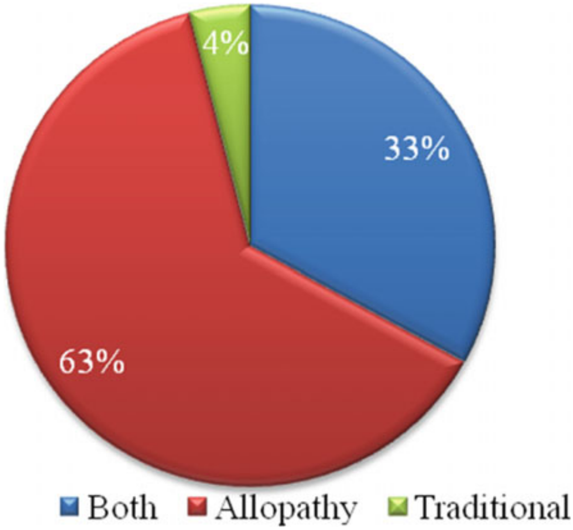


Fig. 5 Medicinal preference for curing major disease viz. cancer, tuberculosis, diabetes etc. by the Soligas of BRTTR. *Source* Nautiyal et al. (2016)

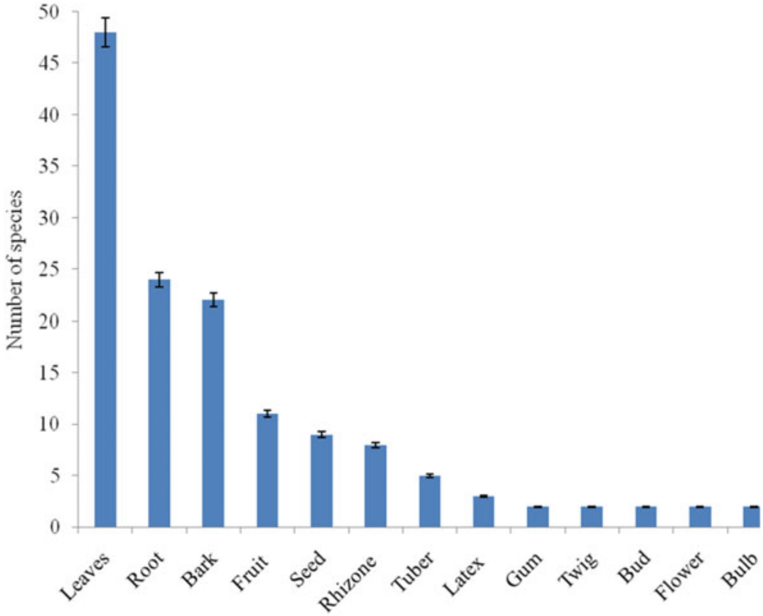


Fig. 6 Different plants parts used in curing various ailments by Soilga tribes of BRTTR. *Source* Nautiyal et al. (2016)

Analysis of both the communities reveals the following:

1. Bhotiya community of central Himalaya region domesticated some species of medicinal plants and Soligas dependency on forest produce including medicinal plants is significantly high.
2. Both the communities depend on medicinal plants for curing ailments as well as income generation which inevitably contributes to their access to food.
3. Many factors which are similar to other parts of the world such as urbanisation, encroachment, destructive harvesting and lack awareness are threatening the cultivation and conservation of medicinal plants in Himalayan as well as at BRTTR region.
4. Primarily both the communities rely on medicinal plants as subsidiary occupation.

Strength

1. Demand for medicinal plants is increasing. India is one of the largest producer along with China sharing more than 40 percent of global biodiversity
2. Medicinal plant sector offers one million employment opportunities for local communities in India.
3. Traditional medicinal plants serve as alternative therapy.
4. Suitable for cultivation and income generation for promoting subsistence economy.
5. Cultivation promotes conservation and preservation of traditional ethno-medicinal knowledge.

Weakness

1. Unsustainable ways of harvesting and unrestricted marketing.
2. Lack quality standards and low price.
3. Completely unregulated, scattered and unpriortised sector.
4. Lack of integrated policies and programmes.
5. Lack of institutional support for folklore and traditional medicines for entrepreneurship.
6. Policy vaccum and lack of coordination among stakeholders
7. Lack of reliable pricing and profitable levels.
8. Lack of baseline data.
9. Deficient toxicology studies and standard preparations.

Opportunities

1. Increase in demand for medicinal plants.
2. Financial assistance and income generating opportunities.
3. Exposure to international market.
4. Addressing institutional setbacks.
5. Development of agro-technological packages under different ecological conditions.
6. Ex-situ conservation through establishment of gene-banks.
7. Encouraging contract farming of medicinal plants.
8. Opportunities of Organic farming of medicinal plants.

Threats

1. Depletion of natural resources.
2. Problems of exploitation and impoverishment of gatherers.
3. Globalisation and Commercialisation and unsustainable practices.
4. Lack of effective enforcement of environmental regulations.
5. Unregulated harvesting of medicinal and aromatic plants.
6. Lack of infrastructure and agro-technology.
7. Lack of in-situ and ex-situ conservation methods.
8. Medicinal plant trade is inefficient, imperfect, informal and opportunistic.

SWOT Analysis of Medicinal Plants in India and Food Security

10 Conclusion

Available literature ample prove that rich biodiversity of medicinal plants in India constitute invaluable economic potential as well as livelihood for various local communities in terms of generating income opportunities. Harnessing medicinal plant cultivation for improved food security in India is the area which has been largely underexplored. Medicinal plants particularly, herbal plants have been contributing significantly to the livelihood of Indian tribes who rely on benefits from traditional practices for both monetary and non-monetary benefits. Therefore, the correlation between cultivation of medicinal plants for improved food security especially in India cannot be overruled.

Despite a great heritage of medicinal plants in India, major concern has been accelerated anthropogenic pressure inducing loss of biodiversity of medicinal plants. Further, though commercial production of medicinal plants gained momentum in the past few years, but diversification of land for developmental projects and lack institutional support and infrastructure has constrained the expansion for utilising medicinal plants for sustaining the people's livelihood. Once economic potential and value chain improved, medicinal plants have enormous potential of generating income opportunities and thereby reduce poverty.

Better management and conservation of medicinal plants imply addressing shortcoming and threats of depletion, exploitation and impoverishment of natural resources. There must be effective regulation of medicinal plant cultivation against commercialisation and unsustainable practices. Also institutional coordination to promote in situ and ex situ conservation would go a long way in addressing depletion of medicinal resources. Besides, research to understand the relationship between household income and market potential of medicinal plants will help to promote sustainable conservation practices and enhance their contribution to the local people's lievelihood.

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Plant Diversity and Distribution Pattern in Tropical Dry Deciduous Forest of Eastern Ghats, India

Durai Sanjay Gandhi and Somaiah Sundarapandian

Abstract Vegetation of a tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats, India was analyzed by laying 30 square plots (1 ha). A total of 210 plant species (75 trees and herbs, 27 shrubs and 33 climbers) were enumerated. Species richness ranged 35–84/ha. The number of tree, shrub, herb and climber species in plots varied from 7–28/ha, 5–14/0.125 ha, 10–36/50 m^2 and 3–23/0.125 ha respectively. The basal area of trees ranged 7.23–43.05 m^2/ha. Shannon's index ranged from 0.716 to 2.343 for tree species. *Albizia amara* was the dominant tree species except for plot nos. 24 and 25, where *Chloroxylon swietenia* was dominant. In shrub community, *Lantana camara* and *Clausena heptaphylla* were the dominant species. *Sida cordifolia* and *Ageratum conyzoides* were the most abundant species in the herbaceous community. In climbers, *Pterolobium hexapetalum* was the dominant species. The dominance of ruderal weeds and exotics in the understory indicates that this forest is under the threat of anthropogenic pressure although it has been declared as a reserve forest. The present study reveals that differences in microclimate, level and kind of anthropogenic perturbation, and edaphic characteristics among the plots could be the reason for the significant spatial variation in species richness and density among the plots even though they are located within 10 km radius. However, this forest ecosystem restores rich flora similar to other tropical dry forests in India and elsewhere. To impede the plant invasion, timely measures are to be adopted to eliminate invasive species in order to retain and conserve the native diversity.

Keywords Eastern Ghats · Biodiversity · Tropical forest · Anthropogenic disturbance · Vegetation structure · Species composition

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1 Introduction

Tropical forests are biodiversity-rich centres on earth and harbour approximately two-thirds of all living organisms (Hughes et al. 1997) including 96% of tree species (Poorter et al. 2015). The tropical forest biome comprises of diverse ecosystems between Tropic of Cancer and Tropic of Capricorn and spans across the Americas, Asia, Africa and Australia, and has the richest biodiversity with a unique environment. According to Miles et al. (2006), dry deciduous forest covers 6% (1,048,700 km^2) of the tropics. Around 40% of the earth's subtropical area is occupied by open or closed forest and of which 42% are tropical dry deciduous forest, 33% are moist forest and 25% are wet forest (Murphy and Lugo 1986). About 54.2% of the world's tropical dry forests are in South America and the rest are equally distributed in North and Central America, Eurasia, Africa, Southeast Asia and Australasia (Miles et al. 2006). In southeast Asia, 30% of forests in the mainland are classified as dry forest (Blackie et al. 2014).

Tropical forests of Asia, especially Eastern and Western Ghats are under threat owing to human activities and are consequently, being replaced by inferior species (Bahuguna 1999). Tropical rain forests are extensively studied compared to dry forests (Losos and Leigh 2004). Although tropical dry deciduous forests are highly degraded and converted to other land uses, they had little attraction among the researchers and the general public (Bullock et al. 1995; Rundel et al. 1995). Tropical dry deciduous forests are rich in economically important species and are known to provide high potential timber revenue (Mohapatra and Tewari 2005). Hence, there is a growing interest on dry forests in the recent past (Miles et al. 2006). Dry deciduous forests are one of the most exploited ecosystems in the world (Murphy and Lugo 1986; Janzen 1988; Gentry 1992), as they are more prone to fire in the dry season (Giriraj et al. 2010). Documentation of biodiversity patterns is essential to prioritize areas for conservation programmes (Villasenor et al. 2007). Information on structure and composition of tropical dry deciduous forests is needed to conserve and restore these threatened ecosystems. The quantitative floristic analysis of the forest provides the necessary information for future planning and management (Phillips et al. 2003).

India, being a mega-diverse country, covers about 2% of the global forest area and is one of the richest repositories due to the presence of different types of vegetation and they hold unique flora and fauna. Tropical forest in India occupies 86% of the total forest cover (Singh and Singh 1988), of which 54% are dry deciduous, 37% are moist deciduous and the remaining is wet-/semi-evergreen (Kaul and Sharma 1971). The Eastern Ghats are a fragmented hill-chain, starting from Odisha to Tamil Nadu. Studies exploring the structure and composition of forests in Eastern Ghats of Tamil Nadu are limited (Kadavul and Parthasarathy 1999a, b, 2000; Chittibabu and Parthasarathy 2000a, b, 2001; Jayakumar et al. 2002; Pragasan and Parthasarathy 2010; Muthumperumal and Parthasarathy 2013; Sundarapandian et al. 2015). However, studies on plant diversity in tropical dry deciduous forest Sathanur reserve forest is almost nil except for preliminary result output of us (Gandhi and Sundarapandian 2014a, b). Hence present study is intended to study the vegetation structure and species composition of the tropical dry deciduous forest at Sathanur reserve forest of Eastern Ghats. Furthermore, an attempt was also made to understand the factors responsible for spatial variation in plant diversity.

2 Materials and Methods

2.1 Study Area

Sathanur reserve forest (longitude 78°51′10″ and latitude 12°4′48″), a part of Chennakesava hills, Tamil Nadu, India, spread over 870 ha (Fig. 1) was chosen for the present study belonging to a part of Eastern Ghats, India. The Eastern Ghats experience heavy pressure due to illegal logging, collection of fodder, fuelwood, medicinal plants, etc. and thereby are losing its vegetation at an alarming rate (Jayakumar et al. 2002). The vegetation of this region is dry deciduous forest type (Type 7/CI of Champion and Seth 1968) based on the Champion and Seth (1968) classification of Indian forests.

Sathanur Reserve forest receives a bimodal pattern of rainfall, with maximum rain during north-east monsoon (September–December) and very less and inconsistent rainfall during the south-west monsoon (May–July). The average annual rainfall for 44 years (1972–2015) was 965.49 mm and mean monthly maximum temperatures ranged between 28 and 37 °C while mean monthly minimum temperatures varied from 19.6 to 26.8 °C (Fig. 2). The major soil types in the district are red loam and

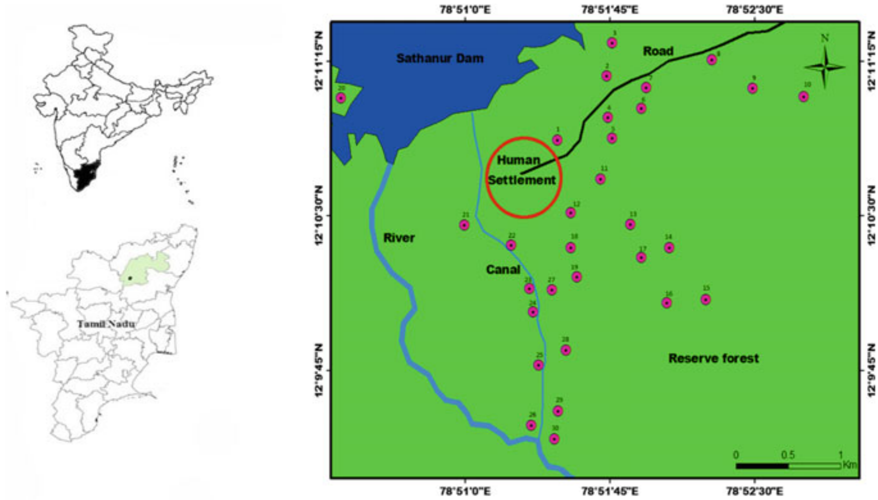

Fig. 1 Location of 30 one-hectare study plots (indicated by pink dots with numbers) in the Sathanur reserve forest of Eastern Ghats, India

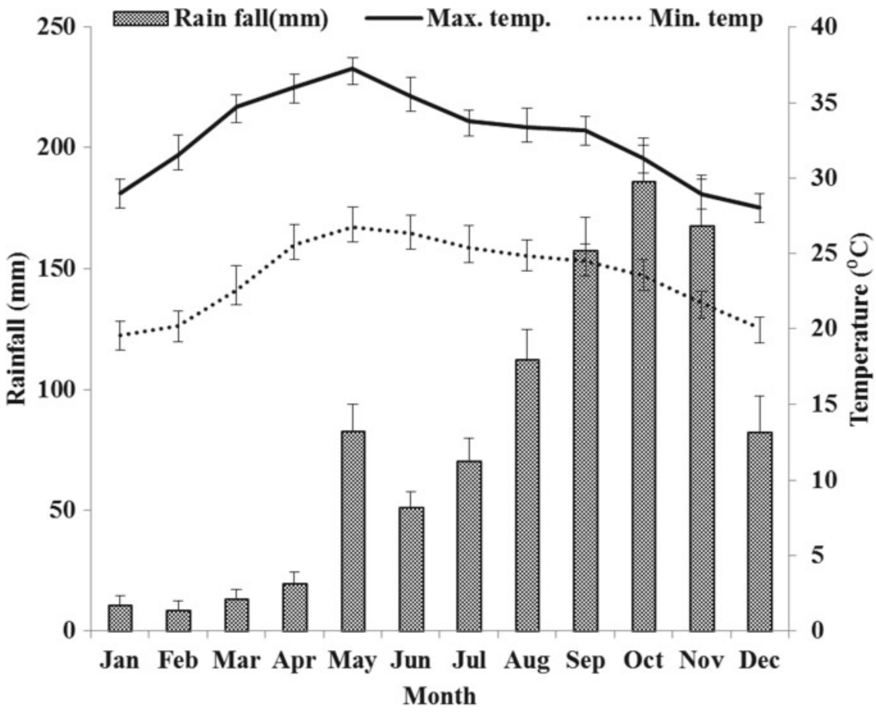

Fig. 2 Mean monthly rainfall (44 years) and temperature (study period) of the Sathanur reserve forest, Eastern Ghats

black soil and the red loam soil is predominantly found in Sathanur reserve forest (NADP 2008). The texture of the soil was sandy loam in most of the plots while the plots near to the rivulet were sandier than the other study sites. However, pebbles are abundant in the soil in most of the plots.

2.2 *Vegetation Analysis*

Thirty square plots of 1 ha each were laid approximately at 500 m intervals in the Sathanur reserve forests during the period of November 2013 to February 2015 (Fig. 1) which were further sub-gridded into 10 m × 10 m size (100 m^2) quadrats as easy, workable units. All the individual plants with ≥10 cm GBH were enumerated and their girth were measured at 1.37 m from the ground level. In multi-stemmed trees, GBHs were measured separately, after which basal area was calculated and summed up. Within each plot, 50 quadrats of 5 m × 5 m were laid in a systematic sampling method to enumerate shrubs and climbers. Similarly, fifty quadrats of 1 m × 1 m each were laid for herbs in each 1 ha plot and studied during October and November (peak growth period). Shrubs and herbs, the diameter was measured at 3 cm above the ground of each individual using vernier caliper. Plant specimens were collected and identified with confirmation of taxonomist using floras (Gamble and Fischer 1987; Matthew 1991). The cut stems were enumerated in all the plots and the disturbance index was computed based on the number of cut stems divided by the total number of stems including cut stems (Rao et al. 1990). The vegetation data collected in each plot was analyzed for analytical and synthetic quantitative characteristics. The diversity indices were computed using the freely downloadable PAST 3.1 program (version 3.1; Øyvind Hammer, Natural History Museum, University of Oslo). Importance value index (IVI) was the sum of the values of relative frequency, relative density, and relative basal area (Curtis and McIntosh 1950). The abundance to frequency (A/F) ratio for different species was determined by following Whitford (1949). The ratio indicates regular (<0.025), random (0.025–0.050), and contagious (>0.050) distribution pattern.

Some plots (plot nos. 1–10) in the present study were laid near roads, human settlement or the agricultural fields which are more vulnerable to human exploitation. Although the study area is a reserve forest, locals frequently cut trees and collect firewood, lop branches and graze their cattle. Illegal selective cutting of *Chloroxylon swietenia* for fencing, agricultural tools and other domestic purposes and *Albizia amara* for firewood are quite frequent in this forest. Plots 11–20 are relatively less disturbed than the other plots. Study plots (plot nos. 21–30) were laid on both the sides of a rivulet from Ponnaiyar river. In general, the plots near the rivulet are also subjected to human disturbances. These plots had a rocky terrain. People regularly use the rivulet for day to day activities. In addition, it also serves as a source of drinking water for cattle and hence, these plots are also under high anthropogenic pressures. Soil moisture and pH values showed wide variation among the study plots. Soil pH ranged from 5.9 to 7.1 and the moisture content ranged from 1.28 to 24.0%. The mean soil bulk density value of the three layers ranged from 1.21 to 1.82 g/m^3. Coarse fragment (>2 mm size) fraction in the soil showed wide variations (33.9% of samples contain coarse fractions in all the three depths; 10.2% samples contain coarse fractions in surface (0–10 cm) and middle (10–20 cm) layers; 15.3% samples contain coarse fractions in middle and bottom layers (20–30 cm); 6.7% samples have coarse fractions only in the bottom layer) among the plots, samples and depths. However, 33.9% of the samples collected did not have any coarse fragment (Gandhi 2016; Gandhi and Sundarapandian 2017).

3 Results

3.1 Species Richness and Diversity

A total of 210 plant species belonging to 163 genera and 63 families were enumerated from 30 one-hectare plots in the tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats. Among these, trees and herbs formed the major proportion represented by 75 (35.71%) species each followed by climbers (15.71%) and shrubs (12.86%). The total species richness of study plots ranged from a minimum of 35 species/ha to a maximum of 84 species/ha with a mean of 61.5 ± 2.5 species/ha (Table 1). Among different life-forms, the species richness varied from 7 to 28 species/ha for trees; 10–36 species/50 m^2 for herbs; 5–14 species/0.125 ha for shrubs and 3–23 species/0.125 ha for climbers. We encountered a total of 17,525 tree stems (≥10 cm GBH) from 30 one-hectare study plots. The density ranged from 336 stems/ha to 1075 stems/ha with a mean of 584 ± 38 stems/ha. For climbers and shrubs, it ranged from 9–252 individuals/0.125 ha and 247–969 individuals/0.125 ha respectively. The density of understory species varied considerably from 875 to 6567 individuals per 50 m^2. The total basal area registered by trees across the study plots was 561.3 m^2/ha and on individual plot, their basal area ranged from 7.2 to 43.1 m^2/ha, with a mean of 18.7 ± 1.5 m^2/ha. Similarly, for shrubs and climbers, it ranged from 0.16 m^2/ha to 0.8 m^2/ha and 0.06 m^2/ha to 3.3 m^2/ha respectively. The mean basal area for herbs in the study plots was 3.95 ± 0.3 m^2 per 50 m^2 and it ranged from 0.95 to 6.6 m^2 per 50 m^2. The diversity index, Shannon value ranged from 0.72–2.3 for tree species; 0.81–1.9 for shrubs; 1.16–2.8 for herbs and 0.24–2.8 for climbers (Table 2). Dominance index of tree species ranged from 0.14 to 0.7 with a mean of 0.4. Fisher's alpha index ranged from 1.25–6.36 for trees, 0.75–2.86 for shrubs, 1.23–5.4 for herbs and 0.76–8.1 for climbers.

3.2 Species Composition

Among 75 tree species enumerated, *Albizia amara* was the most dominant tree species represented by 9871 individuals which is almost 56% of the total stems enumerated from 30 one-hectare study plots (Table 3). The other dominant tree species in the study plots were *Chloroxylon swietenia* (3171 individuals), *Azadirachta indica* (553 individuals), *Pongamia pinnata* (477 individuals) and *Acacia catechu* (442 individuals).

The top five species together comprised 82.8% of the total tree species' density (Table 3). In contrast, 32 species including *Strychnos nux-vomica*, *Gmelina asiatica* and *Cassia fistula* were represented by <10 individuals and four species viz. *Borassus flabellifer*, *Cordia monoica*, *Dalbergia oliveri*, and *Delonix elata* were represented by just one individual across the study plots. *Lantana camara* (4661), *Clausena heptaphylla* (3970) and *Tarenna asiatica* (3186) were the predominant shrub species encountered across the study plots. These three species together contributed to 81% of the total shrub species density. However, 11 species among 27 were represented by <10 individuals and four species viz. *Allophylus serratus*, *Cadaba fruticosa*, *Grewia abutilifolia* and *Ziziphus rugosa* were represented by a single individual in all the study plots. The herbaceous community of the study plots was dominated by *Sida cordifolia* (22,038 individuals), *Ageratum conyzoides* (13,510 individuals) and *Sida acuta* (9245 individuals). Among 75 species, two species including

Table 1 Summary of plant diversity inventory carried out in 30 one-hectare plots of tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats (T—tree, S—shrub, H—herb, C—climbers)

Plot No.	Species richness					Individuals				Basal area (m^2/ha)			
	T[a]	S[b]	H[c]	C[b]	Total	T	S	H	C	T	S	H	C
1	17	12	29	11	69	821	595	3294	78	8.4	0.65	6.53	1.37
2	11	10	23	10	54	797	620	3104	53	17.4	0.60	4.36	0.51
3	12	12	32	14	70	937	575	3234	52	18.6	0.70	3.99	0.42
4	11	10	33	10	64	1075	515	3499	55	24.9	0.61	3.62	0.59
5	17	8	28	21	74	864	481	2581	114	19.5	0.53	2.35	1.40
6	12	10	23	10	55	1000	467	3946	32	19.6	0.34	3.35	0.39
7	21	9	36	11	77	797	247	4514	33	25.1	0.41	5.71	0.87
8	7	9	29	10	55	336	340	2791	64	14.7	0.41	3.03	0.42
9	11	13	33	12	69	438	267	2658	58	9.8	0.52	3.00	1.85
10	21	9	34	10	74	438	333	2961	73	20.7	0.43	2.68	1.15
11	25	11	26	10	72	612	423	3274	86	25.6	0.16	2.63	1.41
12	16	9	29	11	65	456	408	3521	71	10.3	0.33	3.64	1.03
13	28	5	28	10	71	512	358	3065	70	43.1	0.25	3.38	1.41
14	20	13	28	23	84	406	329	4474	130	19.9	0.45	3.81	3.28
15	18	14	28	16	76	435	969	2960	184	30.3	0.80	2.76	0.52

(continued)

Table 1 (continued)

Plot No.	Species richness					Individuals				Basal area (m^2/ha)			
	T[a]	S[b]	H[c]	C[b]	Total	T	S	H	C	T	S	H	C
16	21	14	17	21	73	726	873	875	199	29.4	0.40	0.95	1.03
17	26	10	31	13	80	622	344	6258	97	26.0	0.45	6.41	1.26
18	27	9	21	9	66	561	349	4062	51	15.1	0.44	4.48	0.52
19	24	8	33	13	78	400	481	2595	52	17.9	0.39	2.45	1.39
20	20	6	23	9	58	746	424	4649	53	31.4	0.70	6.28	1.60
21	21	8	22	10	61	449	863	2779	252	24.5	0.36	1.94	0.63
22	12	5	15	3	35	414	589	4185	38	11.3	0.38	3.94	0.20
23	12	8	17	5	42	484	572	5104	50	14.0	0.39	6.59	0.06
24	24	6	11	5	46	500	344	5392	9	8.8	0.31	3.43	0.29
25	25	9	14	3	51	629	290	6567	16	7.2	0.31	4.07	0.45
26	26	7	12	5	50	425	385	3932	43	11.7	0.19	4.39	0.70
27	18	9	16	3	46	373	383	2539	20	11.1	0.17	4.52	1.32
28	15	6	17	4	42	367	521	3789	62	12.9	0.32	5.67	0.30
29	22	6	13	3	44	525	578	3092	20	19.7	0.27	3.88	1.09
30	17	8	10	8	43	380	671	4228	21	12.7	0.24	4.56	0.81

[a] No./ha
[b] No./1250 m^2
[c] No./50 m^2

Table 2 Diversity indices of four dynamic plant life forms in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats (T—tree, S—shrub, H—herb, C—climbers)

Plot No.	Dominance index				Shannon's index				Fisher alpha			
	T	S	H	C	T	S	H	C	T	S	H	C
1	0.41	0.32	0.15	0.21	1.49	1.37	2.33	1.97	4.04	2.13	4.38	3.49
2	0.56	0.30	0.14	0.17	0.85	1.37	2.28	2.04	1.81	1.69	3.37	3.65
3	0.62	0.26	0.13	0.10	0.77	1.58	2.48	2.48	1.94	2.15	4.39	6.29
4	0.68	0.29	0.12	0.22	0.72	1.43	2.49	1.93	1.71	1.76	5.04	3.58
5	0.35	0.32	0.11	0.10	1.52	1.38	2.51	2.69	3.00	1.57	4.93	7.56
6	0.66	0.22	0.19	0.11	0.74	1.71	2.08	2.26	1.92	1.58	3.24	4.99
7	0.29	0.23	0.10	0.14	1.80	1.73	2.61	2.21	3.95	1.83	5.34	6.30
8	0.59	0.24	0.13	0.28	0.89	1.62	2.42	1.75	1.25	1.70	4.51	3.32
9	0.35	0.25	0.10	0.26	1.28	1.72	2.80	1.89	2.05	2.86	5.31	4.59
10	0.32	0.23	0.13	0.15	1.56	1.65	2.64	2.07	4.60	1.71	5.39	3.14
11	0.27	0.37	0.21	0.32	1.87	1.32	1.90	1.60	5.24	2.07	2.19	3.11
12	0.37	0.34	0.34	0.22	1.32	1.40	1.27	1.92	3.23	1.63	1.32	3.64
13	0.27	0.61	0.47	0.28	2.03	0.81	1.16	1.77	6.36	0.82	1.69	3.19
14	0.36	0.33	0.09	0.09	1.60	1.48	2.70	2.80	4.41	2.70	5.33	8.11
15	0.36	0.23	0.20	0.36	1.62	1.78	2.12	1.75	3.79	2.32	3.15	4.21
16	0.46	0.25	0.16	0.26	1.01	1.74	2.30	2.15	3.03	2.37	3.85	5.93

(continued)

Table 2 (continued)

Plot No.	Dominance index				Shannon's index				Fisher alpha			
	T	S	H	C	T	S	H	C	T	S	H	C
17	0.57	0.30	0.34	0.23	1.14	1.66	1.71	1.84	5.75	1.93	4.25	4.04
18	0.25	0.17	0.18	0.27	2.03	1.95	2.02	1.72	5.92	1.69	2.90	3.17
19	0.17	0.30	0.34	0.12	2.21	1.46	1.42	2.31	5.61	1.36	1.23	5.56
20	0.34	0.34	0.28	0.48	1.48	1.28	1.53	1.27	3.78	1.22	1.96	2.08
21	0.36	0.27	0.47	0.27	1.72	1.38	1.26	1.65	4.57	0.75	1.53	2.93
22	0.63	0.21	0.20	0.90	0.89	1.69	1.84	0.24	2.31	1.32	1.74	0.76
23	0.43	0.23	0.17	0.59	1.17	1.60	2.18	0.88	2.69	1.03	3.26	1.38
24	0.13	0.28	0.21	0.23	2.34	1.54	1.97	1.52	4.98	1.76	2.28	4.63
25	0.18	0.25	0.21	0.37	2.07	1.60	1.83	1.04	4.69	1.22	2.29	1.09
26	0.36	0.29	0.25	0.49	1.68	1.59	1.95	1.02	6.11	1.65	4.26	1.47
27	0.56	0.28	0.10	0.67	1.15	1.50	2.64	0.61	3.95	0.95	3.99	0.98
28	0.48	0.39	0.13	0.76	1.18	1.28	2.45	0.52	3.15	0.93	4.28	0.96
29	0.18	0.42	0.10	0.44	2.19	1.15	2.49	0.93	4.65	0.99	2.99	0.98
30	0.40	0.37	0.15	0.24	1.51	1.28	2.27	1.68	3.65	1.28	4.33	4.72

Table 3 Life form abundance in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

Name of the species	Family	Abundance/30 ha	Mean ± SE
Tree			
Albizia amara (Roxb.) Boivin	Mimosaceae	9871	329.03 ± 35.9
Chloroxylon swietenia DC.	Flindersiaceae	3171	105.70 ± 17.0
Azadirachta indica A. Juss.	Meliaceae	553	18.43 ± 3.18
Pongamia pinnata (L.) Pierre	Fabaceae	477	15.90 ± 4.57
Acacia catechu (L. f.) Willd.	Mimosaceae	442	14.73 ± 4.59
Atalantia monophylla (L.) Correa	Rutaceae	311	10.37 ± 2.85
Canthium dicoccum (Gaertn.) Teijsm and Binn.	Rubiaceae	268	8.93 ± 2.71
Gyrocarpus jacquini Roxb.	Hernandiaceae	262	8.73 ± 3.10
Diospyros ebenum Koen.	Ebenaceae	231	7.70 ± 2.84
Wrightia tinctoria (Roxb.) R.Br.	Apocynaceae	190	6.33 ± 1.31
Drypetes sepiaria (W. and A.) Pax and Hoffm.	Euphorbiaceae	164	5.47 ± 1.47
Ziziphus mauritiana Lam.	Rhamnaceae	156	5.20 ± 1.48
Diospyros ferrea (Willd.) Bakh.	Ebenaceae	155	5.17 ± 3.20
Dichrostachys cinerea (L.) W. andA.	Mimosaceae	154	5.13 ± 2.83
Cassia siamea Lam.	Caesalpiniaceae	103	3.43 ± 2.00
Alangium salvifolium (L. f.) Wang.	Alangiaceae	85	2.83 ± 1.18
Sapindus emarginatus Vahl.	Sapindaceae	73	2.43 ± 1.19
Cleistanthus collinus (Roxb.) Benth.	Euphorbiaceae	67	2.23 ± 1.04
Dalbergia paniculata Roxb.	Fabaceae	53	1.77 ± 0.64
Prosopis juliflora (Sw.) DC.	Mimosaceae	53	1.77 ± 0.83
Syzygium cumini (L.) Skeels	Myrtaceae	50	1.67 ± 0.78
Diospyros montana Roxb.	Ebenaceae	47	1.57 ± 0.71
Moringa concanensis Nimmo	Moringaceae	44	1.47 ± 0.70
Albizia lebbeck (L.) Benth.	Mimosaceae	36	1.20 ± 0.39
Bauhinia racemosa Lam.	Caesalpiniaceae	34	1.13 ± 0.44
Acacia leucophloea Roxb.	Mimosaceae	31	1.03 ± 0.56
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	30	1.00 ± 0.55
Vitex trifolia L.	Lamiaceae	29	0.97 ± 0.51
Erythroxylum monogynum Roxb.	Erythroxylaceae	28	0.93 ± 0.50
Ficus benghalensis L.	Moraceae	27	0.90 ± 0.26

(continued)

Table 3 (continued)

Name of the species	Family	Abundance/30 ha	Mean ± SE
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	27	0.90 ± 0.80
Ailanthus excelsa Roxb.	Simaroubaceae	22	0.73 ± 0.67
Mallotus philippensis (Lam.) Müll. Arg.	Euphorbiaceae	22	0.73 ± 0.42
Premna serratifolia L.	Lamiaceae	17	0.57 ± 0.50
Strychnos potatorum L.	Strychnaceae	17	0.57 ± 0.47
Cassia roxburghii DC.	Caesalpiniaceae	16	0.53 ± 0.53
Pavetta indica L.	Rubiaceae	16	0.53 ± 0.50
Garcinia spicata Hook. f.	Rubiaceae	15	0.50 ± 0.31
Crataeva magna (Lour.) DC.	Capparaceae	14	0.47 ± 0.34
Dolichandrone falcata (Wall. ex DC.) Seem	Bignoniaceae	14	0.47 ± 0.26
Butea monosperma (Lam.) Taub.	Fabaceae	12	0.40 ± 0.18
Delonix regia (Boj. Ex Hook.) Rafin	Fabaceae	12	0.40 ± 0.40
Grewia tiliaefolia Vahl.	Tiliaceae	12	0.40 ± 0.18
Strychnos nux-vomica L.	Strychnaceae	9	0.30 ± 0.27
Tamarindus indica L.	Caesalpiniaceae	9	0.30 ± 0.11
Gmelina asiatica L.	Verbenaceae	8	0.27 ± 0.23
Rhus mysorensis G. Don	Anacardiaceae	8	0.27 ± 0.14
Terminalia arjuna (Roxb. Ex Dc.) W. and A.	Combretaceae	6	0.20 ± 0.12
Tricalysia sphaerocarpa (Dalzell ex Hook.f.) Gamble	Rubiaceae	6	0.20 ± 0.20
Cassia didymobotrya Fresn.	Caesalpiniaceae	5	0.17 ± 0.11
Ixora pavetta Andr.	Rubiaceae	5	0.17 ± 0.14
Acacia nilotica (L.) Willd. ex Delile	Mimosaceae	4	0.13 ± 0.10
Dalbergia sissoo Roxb. ex DC.	Fabaceae	4	0.13 ± 0.10
Eucalyptus tereticornis Smith	Myrtaceae	4	0.13 ± 0.13
Aglaia elaeagnoidea (A. Juss.) Benth.	Meliaceae	3	0.10 ± 0.07
Cassia fistula L.	Caesalpiniaceae	3	0.10 ± 0.07
Ficus glomerata Roxb.	Moraceae	3	0.10 ± 0.10
Gardenia resinifera Roth.	Rubiaceae	3	0.10 ± 0.06
Givotia moluccana (L.) Sreem.	Euphorbiaceae	3	0.10 ± 0.07

(continued)

Table 3 (continued)

Name of the species	Family	Abundance/30 ha	Mean ± SE
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae	3	0.10 ± 0.07
Kleinhovia hospita L.	Sterculiaceae	3	0.10 ± 0.07
Manilkara hexandra (Roxb.) Dubard	Sapotaceae	3	0.10 ± 0.07
Annona squamosa L.	Annonaceae	2	0.07 ± 0.05
Commiphora caudata Engl.	Burseraceae	2	0.07 ± 0.07
Dalbergia lanceolaria L.	Fabaceae	2	0.07 ± 0.05
Drypetes deplanchei (Brongn. and Gris) Merr.	Euphorbiaceae	2	0.07 ± 0.07
Ficus hispida L. f.	Moraceae	2	0.07 ± 0.05
Murraya koenigii (L.) Spreng.	Rutaceae	2	0.07 ± 0.05
Parkinsonia aculeata L.	Fabaceae	2	0.07 ± 0.05
Pisonia sechellarum F. Friedmann	Nyctaginaceae	2	0.07 ± 0.07
Pithecellobium dulce (Roxb.) Benth.	Fabaceae	2	0.07 ± 0.05
Borassus flabellifer L.	Arecaceae	1	0.03 ± 0.03
Cordia monoica Roxb.	Boraginaceae	1	0.03 ± 0.03
Dalbergia oliveri Gamble ex Prain.	Fabaceae	1	0.03 ± 0.03
Delonix elata (L.) Gamble	Caesalpiniaceae	1	0.03 ± 0.03
Shrub			
Lantana camara L.	Verbenaceae	4661	155.37 ± 16.5
Clausena heptaphylla (Roxb.) Wight and Arn.	Rutaceae	3970	132.33 ± 14.7
Tarenna asiatica (L.) Kuntze ex K.Schum.	Rubiaceae	3186	106.20 ± 16.2
Canthium coromandelicum (Burm.f.) Alston	Rubiaceae	592	19.73 ± 4.48
Solanum nigrum L.	Solanaceae	471	15.70 ± 4.91
Barleria longiflora L. f.	Acanthaceae	415	13.83 ± 5.08
Opuntia stricta (Haw.) Haw.	Cactaceae	381	12.70 ± 2.93
Carmona retusa (Vahl) Masamune	Boraginaceae	302	10.07 ± 2.32
Dodonaea angustifolia L. f.	Sapindaceae	140	4.67 ± 2.60
Cassia auriculata L.	Caesalpiniaceae	108	3.60 ± 1.28
Catunaregam spinosa (Thunb.) Tirveng.	Rubiaceae	97	3.23 ± 1.65
Jatropha gossypifolia L.	Euphorbiaceae	66	2.20 ± 0.95

(continued)

Table 3 (continued)

Name of the species	Family	Abundance/30 ha	Mean ± SE
Securinega leucopyrus (Willd.) Muell.	Euphorbiaceae	64	2.13 ± 1.04
Flacourtia indica (Burm. f.) Merr.	Flacourtiaceae	42	1.40 ± 0.76
Ipomoea carnea Jacq.	Convolvulaceae	35	1.17 ± 0.69
Cassia hirsuta L.	Caesalpiniaceae	28	0.93 ± 0.58
Phyllanthus reticulatus Poir.	Euphorbiaceae	9	0.30 ± 0.19
Euphorbia antiquorum L	Euphorbiaceae	7	0.23 ± 0.18
Cassia alata L.	Caesalpiniaceae	5	0.17 ± 0.08
Calotropis gigantea (L.) R. Br.	Asclepiadaceae	4	0.13 ± 0.13
Carissa paucinervia A.DC.	Apocynaceae	3	0.10 ± 0.07
Crotalaria formosa Wight and Arn.	Fabaceae	2	0.07 ± 0.07
Solanum torvum Sw.	Solanaceae	2	0.07 ± 0.07
Allophylus serratus (Roxb.) Kurz	Sapindaceae	1	0.03 ± 0.03
Cadaba fruticosa (L.) Druce	Capparaceae	1	0.03 ± 0.03
Grewia abutilifolia Vent. ex Juss.	Tiliaceae	1	0.03 ± 0.03
Ziziphus rugosa Lam.	Rhamnaceae	1	0.03 ± 0.03
Herb			
Sida cordifolia L.	Malvaceae	22,038	734.60 ± 87.3
Ageratum conyzoides L.	Asteraceae	13,510	450.33 ± 89.2
Sida acuta Burm. f.	Malvaceae	9245	308.17 ± 142
Eragrostis tenella (L.) P. Beauv. ex Roem. and Schult.	Poaceae	8876	295.87 ± 85.5
Aristida hystrix L. f.	Poaceae	8649	288.30 ± 77.1
Aristida setacea Retz.	Poaceae	5497	183.23 ± 141
Evolvulus alsinoides L.	Convolvulaceae	4180	139.33 ± 30.9
Euphorbia hirta L.	Euphorbiaceae	3927	130.90 ± 29.1
Ocimum canum Sims	Lamiaceae	3074	102.47 ± 73.2
Mollugo pentaphylla L.	Molluginaceae	2587	86.23 ± 20.38
Sida cordata (Burm. f.) Borssum Waalkes	Malvaceae	2055	68.50 ± 31.75
Blepharis maderaspatensis (L.) B.Heyne ex Roth	Acanthaceae	2029	67.63 ± 19.23
Tephrosia purpurea (L.) Pers.	Papilionaceae	1930	64.33 ± 24.13
Bulbostylis densa (Wall.) Hand.-Mazz.	Cyperaceae	1856	61.87 ± 14.30
Leucas aspera (Willd.) Link.	Lamiaceae	1484	49.47 ± 7.26

(continued)

Table 3 (continued)

Name of the species	Family	Abundance/30 ha	Mean ± SE
Hybanthus enneaspermus (L.) F. Muell.	Violaceae	1417	47.23 ± 22.84
Cyrtococcum trigonum (Retz.) A.Camus	Poaceae	1229	40.97 ± 15.33
Brachiaria ramosa (L.) Stapf	Poaceae	1208	40.27 ± 19.41
Commelina paleata Hassk. Pl. Jungh.	Commelinaceae	1195	39.83 ± 14.21
Heteropogon contortus (L.) P.Beauv. ex. R. and Schu.	Poaceae	1159	38.63 ± 19.69
Andrographis paniculata (Burm. f.) W. ex Nees	Acanthaceae	1136	37.87 ± 18.58
Apluda mutica L.	Poaceae	1089	36.30 ± 16.68
Achyranthes aspera L.	Amaranthaceae	843	28.10 ± 9.57
Boerhaavia diffusa L.	Nyctaginaceae	672	22.40 ± 20.63
Vernonia cinerea (L.) Less.	Asteraceae	591	19.70 ± 5.25
Tragia involucrata L.	Euphorbiaceae	555	18.50 ± 17.92
Cyperus rotundus L.	Cyperaceae	533	17.77 ± 5.61
Acalypha indica L.	Euphorbiaceae	497	16.57 ± 8.53
Dipteracanthus patulus (Jacq.) Nees	Acanthaceae	466	15.53 ± 14.19
Perotis indica (L.) Kuntze	Poaceae	465	15.50 ± 7.82
Cynodon dactylon (L.) Pers.	Poaceae	416	13.87 ± 6.79
Leonotis nepetifolia (L.) R.Br.	Lamiaceae	407	13.57 ± 5.74
Anisomeles malabarica (L.) R. Br. ex Sims	Lamiaceae	341	11.37 ± 9.91
Parthenium hysterophorus L.	Asteraceae	341	11.37 ± 7.20
Paspalidium flavidum (Retz.) A.Camus	Poaceae	339	11.30 ± 5.78
Gomphrena decumbens C. Martius.	Amaranthaceae	320	10.67 ± 3.60
Indigofera astragalina DC.	Papilionaceae	311	10.37 ± 4.32
Spermacoce ocymoides Burm. f.	Rubiaceae	262	8.73 ± 4.90
Dipteracanthus prostratus (Poir.) Nees	Acanthaceae	259	8.63 ± 8.50
Rostellularia simplex Wight	Acanthaceae	256	8.53 ± 4.68
Corchorus acutangulus L.	Tiliaceae	255	8.50 ± 2.83
Cyperus tenuispica Steud.	Cyperaceae	233	7.77 ± 7.77
Sporobolus virginicus (L.) Kunth	Poaceae	212	7.07 ± 5.89

(continued)

Table 3 (continued)

Name of the species	Family	Abundance/30 ha	Mean ± SE
Desmodium triflorum (L.) DC.	Papilionaceae	181	6.03 ± 4.41
Crotalaria spectabilis Roth	Fabaceae	174	5.80 ± 3.71
Triumfetta rhomboidea Jacq.	Tiliaceae	169	5.63 ± 3.95
Hemidesmus indicus (L.) R. Br.	Asclepiadaceae	152	5.07 ± 4.73
Croton bonplandianus Baillon	Euphorbiaceae	142	4.73 ± 2.30
Asystasia gangetica (L). T. Anderson	Acanthaceae	119	3.97 ± 2.40
Pseudarthria viscida (L) Wight and Arn.	Papilionaceae	119	3.97 ± 2.55
Dactyloctenium aegyptium (L.) P. Beauv.	Poaceae	117	3.90 ± 1.52
Cleome viscosa L.	Capparaceae	111	3.70 ± 2.16
Commelina elegans Kunth	Commelinaceae	108	3.60 ± 1.26
Commelina benghalensis L.	Commelinaceae	96	3.20 ± 2.42
Phyllanthus amarus Schum. and Thonn.	Euphorbiaceae	90	3.00 ± 1.74
Anisomeles indica (L.) Kuntze	Lamiaceae	68	2.27 ± 2.27
Ocimum sanctum L.	Lamiaceae	58	1.93 ± 1.48
Tridax procumbens L	Asteraceae	56	1.87 ± 0.99
Aerva lanata (L.) Juss.	Amaranthaceae	39	1.30 ± 0.61
Chloris inflata Link.	Poaceae	25	0.83 ± 0.55
Datura metel L.	Solanaceae	24	0.80 ± 0.26
Mollugo nudicaulis Lam.	Molluginaceae	23	0.77 ± 0.50
Physalis minima L.	Solanaceae	21	0.70 ± 0.70
Tribulus terrestris L.	Zygophyllaceae	21	0.70 ± 0.70
Abutilon indicum (L.) Sweet	Malvaceae	12	0.40 ± 0.29
Spermacoce articularis L. f.	Rubiaceae	12	0.40 ± 0.40
Acanthospermum hispidum DC.	Asteraceae	8	0.27 ± 0.27
Commelina diffusa Burm.f.	Commelinaceae	8	0.27 ± 0.27
Barleria lupulina Lindl.	Acanthaceae	6	0.20 ± 0.15
Blepharis repens (Vahl) *Roth*	Acanthaceae	6	0.20 ± 0.20
Agave americana L.	Agavaceae	5	0.17 ± 0.11
Hyptis suaveolens (L.) Poit.	Lamiaceae	4	0.13 ± 0.13
Euphorbia thymifolia L.	Euphorbiaceae	2	0.07 ± 0.05
Alysicarpus monilifer (L.) DC.	Papilionaceae	1	0.03 ± 0.03
Amaranthus spinosus L.	Amaranthaceae	1	0.03 ± 0.03

(continued)

Table 3 (continued)

Name of the species	Family	Abundance/30 ha	Mean ± SE
Climber			
Pterolobium hexapetalum (Roth) Sant. and Wagh	Caesalpiniaceae	899	29.97 ± 6.70
Combretum albidum G. Don	Combretaceae	262	8.73 ± 1.90
Acacia caesia (L.) Willd.	Mimosaceae	157	5.23 ± 0.89
Leptadenia reticulata (Retz.) W. and A.	Asclepiadaceae	101	3.37 ± 0.61
Wattakaka volubilis (L. f.) Stapf	Asclepiadaceae	87	2.90 ± 0.65
Diplocyclos palmatus (L.) C. Jeffrey	Cucurbitaceae	70	2.33 ± 0.56
Reissantia indica (Willd.) N. Hallé	Celastraceae	69	2.30 ± 0.45
Ziziphus oenoplia (L.) Miller	Rhamnaceae	58	1.93 ± 0.57
Secamone emetica (Retz.) R. Br. ex Schult.	Asclepiadaceae	55	1.83 ± 0.30
Toddalia asiatica (L.) Lam.	Rutaceae	49	1.63 ± 0.27
Pachygone ovata (Poir.) Diels	Menispermaceae	42	1.40 ± 0.49
Hugonia mystax L.	Linaceae	31	1.03 ± 0.35
Strychnos minor Dennst.	Strychnaceae	29	0.97 ± 0.43
Capparis brevispina DC.	Capparaceae	27	0.90 ± 0.35
Cissus quadarngularis L.	Vitaceae	24	0.80 ± 0.29
Tiliacora acuminata (Lam.) HK. f. and Thoms.	Menispermaceae	22	0.73 ± 0.31
Cansjera rheedii J. F. Gmel.	Opiliaceae	21	0.70 ± 0.28
Plecospermum spinosum Trecur.	Moraceae	21	0.70 ± 0.23
Asparagus racemosus Willd.	Asparagaceae	19	0.63 ± 0.23
Cardiospermum halicacabum L.	Sapindaceae	18	0.60 ± 0.26
Ichnocarpus frutescens (L.) W. T. Aiton	Apocynaceae	16	0.53 ± 0.22
Coccinia grandis (L.) J. Voigt	Cucurbitaceae	12	0.40 ± 0.29
Derris ovalifolia (Wight and Arn.) Benth.	Fabaceae	12	0.40 ± 0.28
Premna latifolia Roxb.	Verbenaceae	11	0.37 ± 0.18
Jasminum angustifolium (L.) Willd.	Oleaceae	9	0.30 ± 0.30
Trichosanthes cucumerina L.	Cucurbitaceae	9	0.30 ± 0.17
Cissampelos pareira L.	Menispermaceae	3	0.10 ± 0.10
Ampelocissus tomentosa (B. Heyne and Roth) Planch.	Vitaceae	1	0.03 ± 0.03

(continued)

Table 3 (continued)

Name of the species	Family	Abundance/30 ha	Mean ± SE
Carissa spinarum L.	Apocynaceae	1	0.03 ± 0.03
Dioscorea bulbifera L.	Dioscoreaceae	1	0.03 ± 0.03
Maerua oblongifolia (Forssk.) A.Rich.	Capparaceae	1	0.03 ± 0.03
Pisonia aculeata L.	Nyctaginaceae	1	0.03 ± 0.03
Toxocarpus kleinii W. and A.	Apocynaceae	1	0.03 ± 0.03

Alysicarpus monilifer and *Amaranthus spinosus* were represented by single individual and seven species viz., *Acanthospermum hispidum*, *Agave americana*, *Barleria lupulina*, *Blepharis boerhaviifolia*, *Commelina diffusa*, *Euphorbia thymifolia* and *Hyptis suaveolens* were encountered with <10 individuals.

Pterolobium hexapetalum (899 individuals) was the predominant climber species across the study plots followed by *Combretum albidum* (262 individuals) and *Acacia caesia* (157 individuals). The top five climber species comprised 70.41% of the total liana density across the study plots. Six species including *Ampelocissus tomentosa*, *Carissa spinarum*, *Dioscorea bulbifera*, *Maerua oblongifolia*, *Pisonia aculeata* and *Toxocarpus kleinii* were represented by mono individuals and three species such as *Cissampelos pareira*, *Jasminum angustifolium* and *Trichosanthes cucumerina* were represented by less than ten individuals. Alien invasive species such as *Lantana camara* (100%) and *Ageratum conyzoides* (93%) were the most commonly distributed and dominant species in shrub and herbaceous communities. Another exotic invasive species *Prosopis juliflora* was also recorded in 43% of plots.

3.3 Importance Value Index and Family Diversity

Albizia amara was the predominant tree species with regard to IVI value across all the 30 one-hectare study plots followed by *Chloroxylon swietenia* and *Acacia catechu* (Tables 4, 5, 6 and 7). Among shrub species, *Lantana camara*, *Clausena heptaphylla* and *Tarenna asiatica* scored greater IVI values, whereas *Sida cordifolia*, *Ageratum conyzoides* and *Sida acuta* were among the predominant herb species in terms of IVI values. *Pterolobium hexapetalum* registered the highest IVI values among climber species followed by *Combretum albidum* and *Acacia caesia*.

Euphorbiaceae was the most speciose plant family across the study plots represented by 17 species followed by Fabaceae and Poaceae with 13 species each (Table 8). Plant families such as Euphorbiaceae and Fabaceae were represented in all the four life-forms studied. However, 24 families were represented by just one species in the present study.

Table 4 Importance value index of top ten tree species in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

Name of the species	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Albizia amara (Roxb.) Bavi	12.2	21.9	213.6	216.7	152.4	26.6	139.4	222.9	17.6	132.3	134.7	150.0	124.0	153.2	164.7
Chloroxylon swietenia DC.	141.2	55.7	6.1	39.3	4.6	49.5	38.5	29.8	75.5	6.6	59.2	87.3	11.3	19.9	0.0
Azadirachta indica A.Juss	15.6	8.4	6.0	22.1	0.0	13.5	22.6	22.3	4.6	47.7	2.3	6.5	1.9	5.4	17.8
Pongamia pinnata (L.) Pierre	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	13.3	3.2	4.4	43.7	40.0
Acacia catechu (L. f.) Willd.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	28.1	23.3	18.2	15.2	3.2	4.8	8.7
Gyrocarpus jacquini Roxb.	3.3	5.3	3.7	0.8	35.6	4.5	0.0	0.0	0.0	1.4	6.9	5.6	3.8	1.1	0.0
Atalantia monophylla (L.) Correa	0.7	0.0	0.6	0.7	0.6	0.0	18.4	1.0	2.4	5.7	17.6	0.9	6.1	4.7	1.7
Wrightia tinctoria (Roxb.) R.Br.	0.9	0.0	5.7	3.9	1.8	6.8	1.3	17.6	4.3	0.6	2.7	5.3	3.4	1.6	3.6
Diospyros ebenum Koen.	2.0	0.0	2.5	1.7	0.0	0.0	17.3	0.0	6.6	6.6	0.8	0.0	14.1	18.6	7.7
Drypetes sepiaria (W. and A.) Pax and Hoffm.	0.0	0.9	1.3	1.4	3.5	3.7	2.7	0.0	1.0	1.2	1.3	0.0	3.5	0.0	0.0

(continued)

Table 4 (continued)

Name of the species	Plot number														
	16	17	18	19	20	21	22	13	24	25	26	27	28	29	30
Albizia amara (Roxb.) Bavi	147.8	29.6	117.3	74.2	139.5	163.7	215.8	183.6	14.8	3.3	164.5	2.5	183.7	81.3	28.2
Chloroxylon swietenia DC.	26.8	24.8	21.2	17.2	76.8	2.3	26.5	72.9	62.3	97.9	17.2	26.3	42.4	16.2	35.6
Azadirachta indica A.Juss	15.0	2.2	21.8	32.5	14.9	2.8	18.4	6.6	12.2	0.7	0.9	1.5	0.8	24.3	0.0
Pongamia pinnata (L.) Pierre	1.4	0.0	2.7	22.6	3.7	39.3	0.0	0.0	1.6	0.0	47.8	0.0	24.1	62.1	6.8
Acacia catechu (L. f.) Willd.	0.0	14.4	1.8	8.3	25.2	0.0	0.0	0.0	5.9	5.2	3.6	5.7	0.0	0.0	2.4
Gyrocarpus jacquini Roxb.	42.9	3.3	1.2	1.3	3.3	7.6	8.3	0.0	1.7	1.0	1.7	9.3	2.4	2.4	7.9
Atalantia monophylla (L.) Correa	0.0	13.2	12.1	0.0	6.8	4.2	0.0	1.5	16.5	24.6	4.4	1.9	0.9	0.0	3.3
Wrightia tinctoria (Roxb.) R.Br.	2.6	0.7	0.0	3.5	3.9	1.4	0.0	9.3	0.0	0.0	8.8	12.4	27.8	0.8	7.3
Diospyros ebenum Koen.	3.5	1.6	31.1	0.0	0.0	5.7	1.0	3.3	0.0	0.0	3.6	1.5	0.0	5.6	2.2
Drypetes sepiaria (W. and A.) Pax and Hoffm.	1.4	2.5	5.8	0.0	0.6	7.7	5.6	13.0	11.2	48.5	0.8	2.1	4.0	0.0	7.6

Table 5 Importance value index of top ten shrub species in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

Name of the species	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lantana camara L.	38.3	86.0	95.6	93.6	38.5	26.5	59.1	108.6	18.5	57.7	43.0	62.4	55.7	129.8	61.3
Clausena heptaphylla (Roxb.) W. and A.	62.7	72.8	75.5	56.5	94.4	63.5	62.5	75.1	86.6	95.0	58.5	118.4	72.9	94.7	48.4
Tarenna asiatica (L.) Alston.	106.2	50.7	52.7	53.7	73.9	115.1	91.1	58.8	108.9	65.4	145.8	36.8	107.6	29.7	116.4
Canthium coromandelicum (Burm.f.) Alston.	26.1	4.7	8.3	11.4	16.7	0.0	8.6	8.6	28.7	25.7	30.4	0.0	61.7	4.8	12.3
Opuntia stricta Haw.		11.3	5.5	38.0	2.6	15.4	11.2	0.0	3.4	16.4	4.8	13.8	0.0	4.3	0.0
Solanum nigrum L.	9.7	54.2	5.1	2.1	0.0	3.2	0.0	5.2	0.0	5.1	0.0	0.0	0.0	15.2	24.9
Barleria longiflora L.f.	2.4	0.0	4.8	3.0	2.7	0.0	0.0	0.0	0.0	1.9	6.9	36.6	0.0	1.5	5.5
Carmona retusa (Vahl) Masam.	10.1	2.4	36.2	14.1	13.6	48.1	11.4	12.0	18.4	31.5	0.0	25.3	0.0	6.4	3.1
Cassia auriculata L.	0.0	16.5	4.6	0.0	0.0	1.5	5.0	2.4	13.9	1.4	0.0	3.2	0.0	0.0	0.0
Dodonaea angustifolia L. f.	1.7	0.8	7.2	24.4	48.3	23.7	0.0	1.9	1.3	0.0	0.0	0.0	2.1	0.0	2.7

(continued)

Table 5 (continued)

Name of the species	Plot number														
	16	17	18	19	20	21	22	13	24	25	26	27	28	29	30
Lantana camara L.	54.3	112.7	70.7	84.2	91.2	66.5	205.1	141.3	110.7	38.4	103.1	135.0	45.7	141.8	97.3
Clausena heptaphylla (Roxb.) W. and A.	136.7	53.6	62.5	49.8	82.3	164.3	46.0	47.5	79.6	142.9	50.2	63.9	161.8	75.9	93.6
Tarenna asiatica (L.) Alston.	80.4	22.9	51.4	41.2	56.4	27.9	12.7	61.7	52.1	14.2	37.4	42.9	37.8	50.7	32.1
Canthium coromandelicum (Burm.f.) Alston.	0.0	23.6	34.9	28.7	0.0	17.6	0.0	1.0	0.0	30.7	31.4	5.9	0.0	3.2	4.6
Opuntia stricta Haw.	6.7	6.2	0.0	20.5	14.4	13.5	11.5	5.3	16.7	32.7	39.4	9.7	28.2	5.9	9.6
Solanum nigrum L.	0.9	17.6	18.6	0.0	0.0	0.0	24.7	38.5	0.0	0.0	0.0	20.3	0.0	22.6	25.6
Barleria longiflora L.f.	6.1	0.0	13.0	73.3	37.1	0.0	0.0	0.0	15.5	20.9	35.2	0.0	8.3	0.0	0.0
Carmona retusa (Vahl) Masam.	3.1	0.0	15.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.2	0.0	5.4
Cassia auriculata L.	1.2	5.3	20.7	0.0	0.0	0.0	0.0	3.4	0.0	1.6	0.0	12.9	0.0	0.0	31.8
Dodonaea angustifolia L. f.	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0

Table 6 Importance value index of top ten herb species in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

Name of the species	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sida cordifolia L.	86.2	6.3	73.7	53.7	63.4	57.8	34.6	60.4	64.5	53.6	58.2	29.7	99.7	25.3	53.6
Ageratum conyzoides L.	19.8	28.9	27.5	24.4	7.8	75.5	43.5	39.1	35.6	16.5	70.3	43.8	65.4	52.5	39.0
Sida acuta Burm. f.	27.4	21.4	1.0	11.0	2.5	3.0	1.2	1.5	8.6	0.0	16.3	63.2	16.6	31.3	8.7
Aristida hystrix L.f.	0.9	0.0	18.1	0.5	0.0	5.4	14.3	15.4	3.4	7.1	2.5	0.7	0.0	6.0	1.0
Eragrostis tenella (L.) Beauv.	9.0	4.6	1.1	7.2	17.8	0.0	1.5	0.0	0.0	0.0	17.5	2.7	4.4	8.6	11.5
Evolvulus alsinoides L.	17.3	50.1	35.4	11.0	3.1	18.0	21.7	13.1	10.7	48.1	19.5	15.0	15.9	11.0	36.1
Euphorbia hirta L.	15.6	17.6	26.1	7.4	0.0	14.1	14.4	10.5	2.2	16.0	15.0	14.0	2.2	12.7	33.8
Aristida setacea Retz.	0.0	1.3	0.4	0.0	0.0	26.8	0.0	0.0	0.0	11.1	0.0	0.0	0.5	0.7	7.2
Blepharis maderaspatensis (L.) Roth	0.9	10.4	22.1	55.5	0.0	19.2	1.7	21.7	13.7	21.8	3.2	32.2	3.9	0.0	37.6
Ocimum canum Sims	3.5	0.0	2.0	7.6	1.3	1.8	3.5	9.4	0.0	0.0	4.0	1.6	11.2	7.8	6.2

(continued)

Table 6 (continued)

Name of the species	Plot number														
	16	17	18	19	20	21	22	13	24	25	26	27	28	29	30
Sida cordifolia L.	0.0	38.4	2.8	33.5	108.7	66.2	117.7	113.3	38.0	0.0	40.1	146.7	109.2	70.8	0.0
Ageratum conyzoides L.	0.0	9.1	2.8	22.9	39.1	18.1	0.0	17.3	127.9	10.6	10.9	22.4	34.0	62.7	32.4
Sida acuta Burm. f.	0.0	135.3	0.0	4.6	0.0	10.3	3.9	0.6	0.0	0.0	169.1	1.1	6.9	33.0	0.0
Aristida hystrix L.f.	0.0	0.0	101.3	4.0	3.7	62.8	56.0	43.9	27.8	56.9	0.0	20.6	31.2	21.5	56.2
Eragrostis tenella (L.) Beauv.	0.0	9.0	24.5	6.0	0.0	29.7	68.2	47.0	93.1	5.2	20.5	27.9	57.4	58.2	0.0
Evolvulus alsinoides L.	11.7	9.3	12.8	65.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Euphorbia hirta L.	2.0	6.7	33.2	28.0	23.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Aristida setacea Retz.	0.0	0.0	1.9	4.7	4.3	3.0	0.0	8.3	0.0	163.2	9.9	16.7	2.0	9.1	0.0
Blepharis maderaspatensis (L.) Roth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ocimum canum Sims	15.6	0.3	0.0	2.7	5.0	0.5	1.3	5.3	0.8	3.7	6.6	0.0	0.0	0.9	121.9

Table 7 Importance value index of top ten climber species in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

Name of the species	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Pterolobium hexapetalum (Roth) Santapau and Wagh	119.5	138.5	102.8	154.6	101.0	0.0	81.2	140.7	15.0	62.1	158.6	151.3	70.0	105.8	44.5
Combretum albidum G. Don	12.1	30.5	20.6	22.0	52.1	25.2	71.1	31.8	165.9	85.6	26.4	28.9	16.0	25.9	140.0
Acacia caesia (L.) Willd	18.5	0.0	23.1	26.5	17.8	30.9	28.4	22.3	11.3	25.7	17.9	19.8	29.3	0.0	13.1
Leptadenia reticulata (Retz.) W. et Arn	11.2	16.5	6.1	10.1	7.8	27.0	17.3	23.2	5.8	26.6	19.8	26.4	13.7	9.1	20.9
Wattakaka volubilis (L.f.) Stapf	7.6	0.0	0.0	16.5	7.8	27.6	18.1	9.7	8.3	14.1	16.8	6.7	11.4	21.9	21.6
Ziziphus oenoplia (L.) Miller	27.1	12.2	0.0	0.0	4.0	50.7	16.4	31.7	0.0	51.5	11.7	22.2	11.2	15.2	0.0
Diplocyclos palmatus (L.) C. Jeffrey	10.0	0.0	9.9	17.5	7.3	35.0	8.8	9.6	8.8	8.6	11.2	8.0	17.9	15.6	9.9
Reissantia indica (Willd.) N. Hallé	6.7	8.3	0.0	19.6	4.2	26.5	29.8	14.6	15.5	12.4	16.1	18.3	4.1	9.1	0.0
Secamone emetica (Retz.) R. Br.	7.3	25.3	12.3	6.8	4.3	11.7	11.3	6.6	11.2	5.0	8.3	8.9	8.4	5.4	0.0

(continued)

Table 7 (continued)

Name of the species	Plot number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Toddalia asiatica (L.) Lam.	5.5	14.0	0.0	9.6	6.8	23.9	9.0	9.9	11.8	8.4	13.1	6.1	2.8	8.3	0.0

Name of the species	Plot number														
	16	17	18	19	20	21	22	13	24	25	26	27	28	29	30
Pterolobium hexapetalum (Roth) Santapau and Wagh	65.0	137.2	45.8	106.4	37.4	154.9	104.0	144.6	184.5	10.3	117.2	186.0	265.9	140.8	81.7
Combretum albidum G.Don	151.1	13.6	83.9	27.7	15.0	44.1	0.0	53.2	10.4	278.6	0.0	15.8	16.6	0.0	0.0
Acacia caesia (L.) Willd	0.0	41.3	19.3	96.5	247.6	0.0	63.5	102.2	32.5	11.1	0.0	27.5	0.0	132.5	139.8
Leptadenia reticulata (Retz.) W. and A.	12.7	46.1	20.6	0.0	0.0	0.0	0.0	0.0	25.9	0.0	27.0	0.0	0.0	0.0	0.0
Wattakaka volubilis (L.f.) Stapf	4.6	11.5	13.5	3.0	0.0	29.8	0.0	0.0	9.2	0.0	39.3	0.0	0.0	0.0	10.3

(continued)

Table 7 (continued)

Name of the species	Plot number														
	16	17	18	19	20	21	22	13	24	25	26	27	28	29	30
Ziziphus oenoplia (L.) Miller	25.0	0.0	13.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diplocyclos palmatus (L.) C. Jeffrey	3.4	10.9	4.6	0.0	0.0	0.0	0.0	0.0	13.3	0.0	24.0	0.0	0.0	26.7	0.0
Reissantia indica (Willd.) N. Hallé	7.0	14.4	16.8	0.0	0.0	0.0	0.0	0.0	6.6	0.0	17.4	0.0	0.0	0.0	0.0
Secamone emetica (Retz.) R. Br.	3.1	7.5	11.3	0.0	0.0	0.0	0.0	0.0	5.5	0.0	12.5	32.0	0.0	0.0	0.0
Toddalia asiatica (L.) Lam.	8.4	17.5	11.2	0.0	0.0	0.0	0.0	0.0	12.1	0.0	9.0	0.0	0.0	0.0	0.0

Table 8 Family-wise contribution of all life forms (tree, shrub, herb, lianas) in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats (T—tree, S—shrub, H—herb, C—climbers)

Name of the family	Species					Genus					Density				
	H	C	S	T	Total	H	C	S	T	Total	H	C	S	T	Total
Acanthaceae	8		1		9	5		1		6	4277		415		4692
Agavaceae	1				1	1				1	5				5
Alangiaceae				1	1				1	1				85	85
Amaranthaceae	4				4	4				4	1203				1203
Anacardiaceae				2	2				2	2				38	38
Annonaceae				1	1				1	1				2	2
Apocynaceae		2	1	1	4		2		1	3		2	3	190	195
Arecaceae				1	1				1	1				1	1
Asclepiadaceae	1	3	1		5	1	3	1		5	152	243	4		399
Asteraceae	5				5	5				5	14,506				14,506
Bignoniaceae				1	1				1	1				14	14
Boraginaceae			1	1	2			1	1	2			302	1	303
Burseraceae				1	1				1	1				2	2
Cactaceae			1		1			1		1			381		381
Caesalpiniaceae		1	3	7	11		1	1	2	4		899	141	171	1211
Capparaceae	1	2	1		4	1	2	1	1	5	111	28	1	14	29
Celastraceae		1			1		1			1		69			69
Combretaceae		1		2	3		1		1	2		262		33	295
Commelinaceae	4				4	1				1	1407				1407
Convolvulaceae	1		1		2	1		1		2	4180		35		4215

(continued)

Table 8 (continued)

Name of the family	Species					Genus					Density				
	H	C	S	T	Total	H	C	S	T	Total	H	C	S	T	Total
Cucurbitaceae		2			2		2			2		82			82
Cyperaceae	3				3	2				2	2622				2622
Dioscoreaceae		1			1		1			1		1			1
Ebenaceae				3	3				1	1				433	433
Erythroxylaceae				1	1				1	1				28	28
Euphorbiaceae	6	2	4	5	17	3	2	4	4	13	5213	25	146	258	5642
Fabaceae	1	2	1	9	13	1	2		6	9	174	169	2	565	910
Flacourtiaceae			1		1			1		1			42		42
Flindersiaceae				1	1				1	1				3171	3171
Hernandiaceae				1	1				1	1				262	262
Lamiaceae	7			1	8	5			1	6	5436			17	5453
Liliaceae		1			1		1			1		19			19
Linaceae		1			1		1			1		31			31
Loganiaceae		1			1		1			1		29			29
Malvaceae	4				4	2				2	33,350				33,350
Meliaceae				2	2				2	2				556	556
Menispermaceae		3			3		3			3		67			67
Mimosaceae				7	7				3	3				10,591	10,591
Molluginaceae	2				2	1				1	2610				2610
Moraceae		1		3	4		1		1	2		21		32	53
Moringaceae				1	1				1	1				44	44

(continued)

Table 8 (continued)

Name of the family	Species					Genus					Density				
	H	C	S	T	Total	H	C	S	T	Total	H	C	S	T	Total
Myrtaceae				2	2				2	2				54	54
Nyctaginaceae	1	1		1	3	1	1			2	672	1		2	675
Oleaceae		1			1		1			1		9			9
Opiliaceae		1			1		1			1		21			21
Papilionaceae	5				5	5				5	2542				2542
Poaceae	13				13	12				12	29,281				29,281
Rhamnaceae		1	1	1	3		1			1		58	1	156	215
Rubiaceae	2		3	6	11	1		2	6	9	274		3875	313	4462
Rutaceae		1	1	2	4		1	1	2	4		49	3970	313	4332
Sapindaceae		1	2	1	4		1	2	1	4		18	141	73	232
Sapotaceae				1	1				1	1				3	3
Simaroubaceae				1	1				1	1				22	22
Solanaceae	2		2		4	2		1		3	45		473		518
Sterculiaceae				1	1				1	1				3	3
Strychnaceae				2	2				1	1				26	26
Tiliaceae	2		1	1	4	2			1	3	424		1	12	437
Ulmaceae				1	1				1	1				3	3
Verbenaceae		1	1	2	4			1	2	3		11	4661	37	4709
Violaceae	1				1	1				1	1417				1417
Vitaceae		2			2		2			2		25			25
Zygophyllaceae	1				1	1				1	21				21

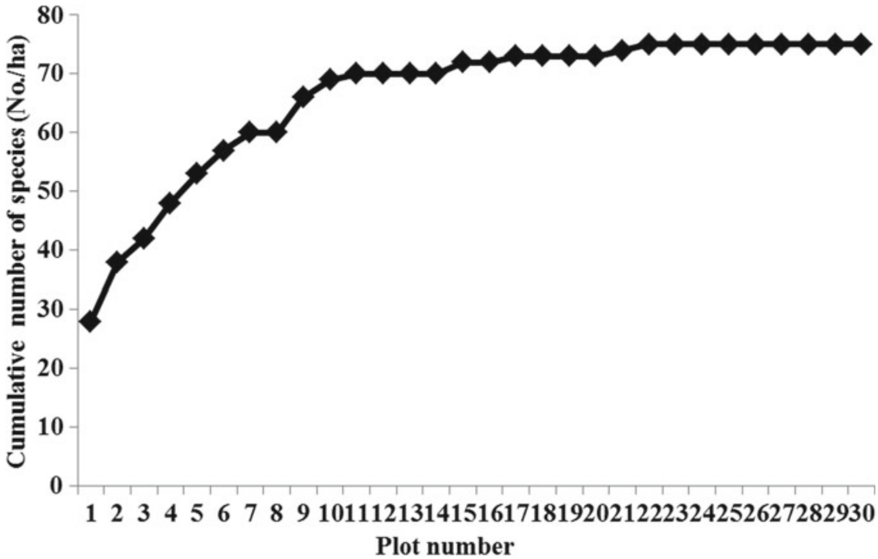

Fig. 3 Species-area curve of plant species (all life forms) in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

3.4 Species-Area Curve

Species-area curve for plant diversity of tropical dry deciduous forest of all life forms (trees, shrubs, herbs, climbers) of 30 one-hectare plots pooled data showed the number of species in all the plots increased initially, steeped up to 13 ha followed by gradual rise, until the sampling reached 23 ha after which, it flattened (Fig. 3). This indicates that sampling of 23 ha is sufficient to record the species richness of the study area. Hence, coverage of 30 ha sampling has been done in the present study exhibits the current status of Sathanur reserve forest.

3.5 Diameter Class Distribution

The density and species richness of trees decreased with increasing tree diameter class (DBH) across the study plots (Figs. 4 and 5). This pattern was also consistent with dominant tree species like *Albizia amara*, *Chloroxylon swietenia*, *Pongamia pinnata*, and *Azadirachta indica* which showed more or less similar trend in diameter class distribution (Fig. 6). Overall, the juvenile population of trees (3.2–10 cm DBH) contributed 50.3% of the total tree density, whereas, adult trees constituted 49.7%.

We screened all the multi-stemmed tree individuals in 30 one-hectare plots and observed a maximum of nine branches below 1.37 m height (Fig. 7). The presence of multiple stems was more prevalent among *Albizia amara* and *Pongamia pinnata*.

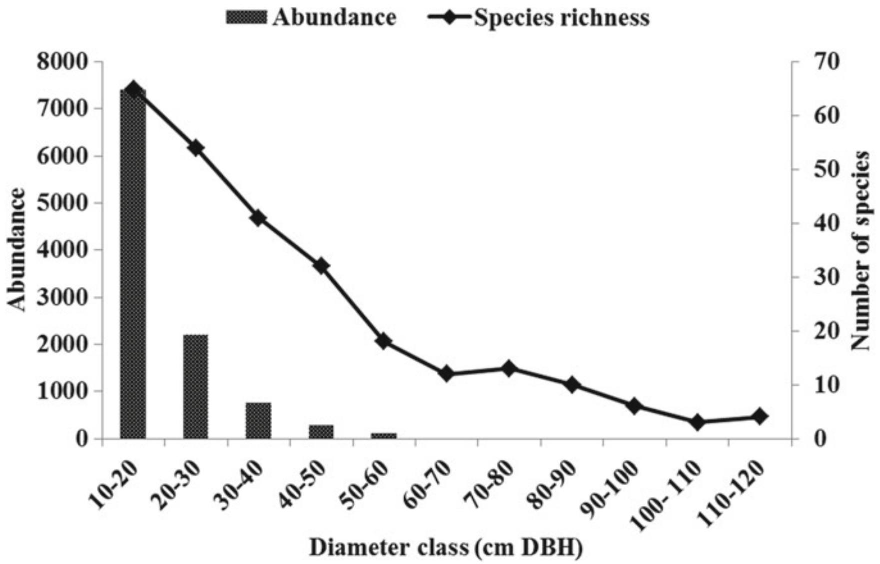

Fig. 4 Diameter class-wise distribution of species richness and abundance of trees in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

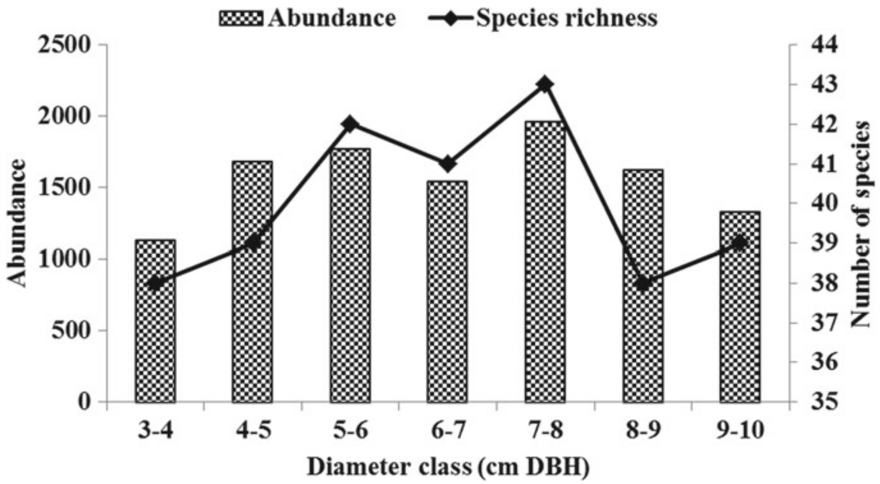

Fig. 5 Diameter class-wise distribution of species richness and density of juvenile population of tree species in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

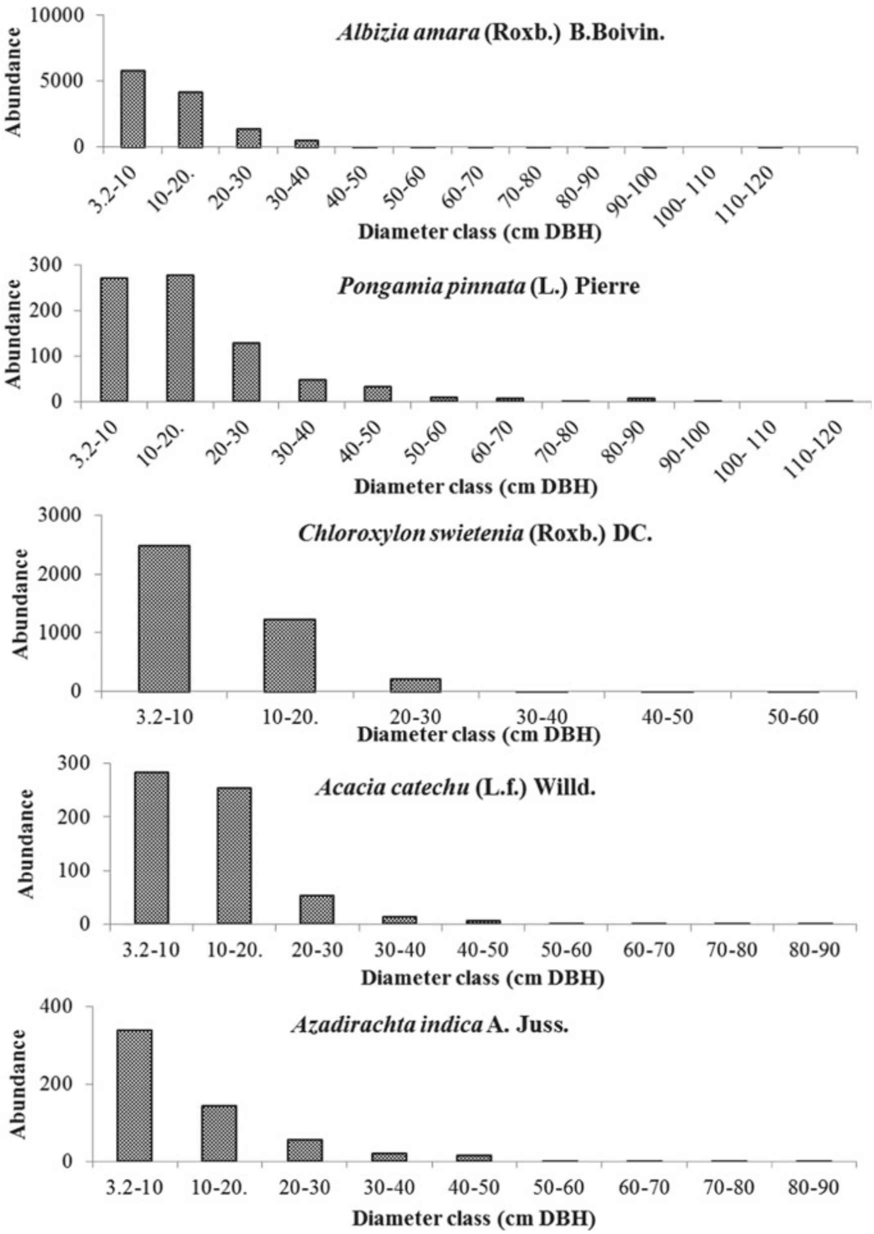

Fig. 6 Diameter class-wise distribution of dominant tree species in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

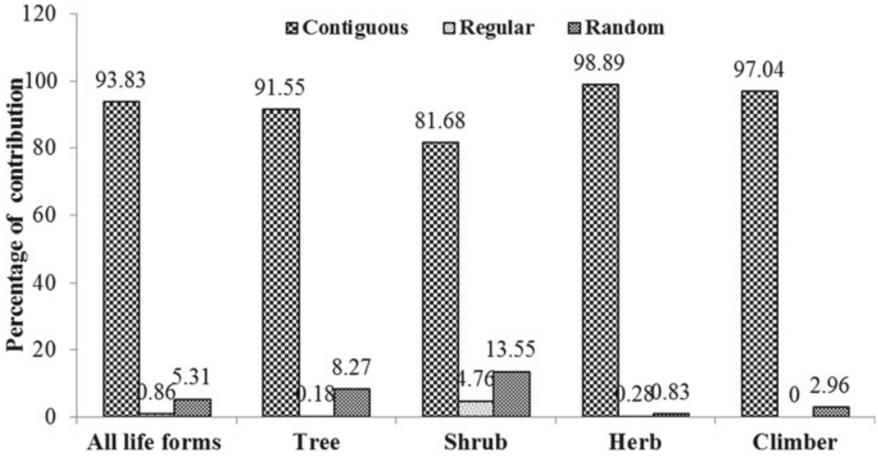

Fig. 7 Distribution patterns of species in a community in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

For calculating the disturbance index, we screened the presence of cut stems and damaged stems in each one-hectare study plot and found that a total of 1335 were removed from the base and 122 individuals were damaged. Disturbance index across the study plots ranged from 0.01 to 0.25 (Fig. 8). The most number of cut stems in the study plots belonged to *Albizia amara* and *Chloroxylon swietenia* followed by *Acacia catechu* and *Pongamia pinnata*.

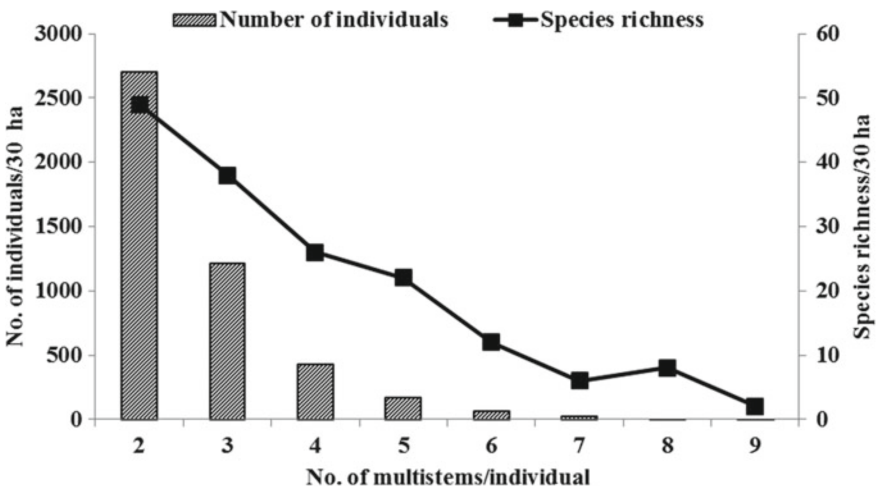

Fig. 8 Contribution of multi-stemmed trees to no. of individuals and species richness in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

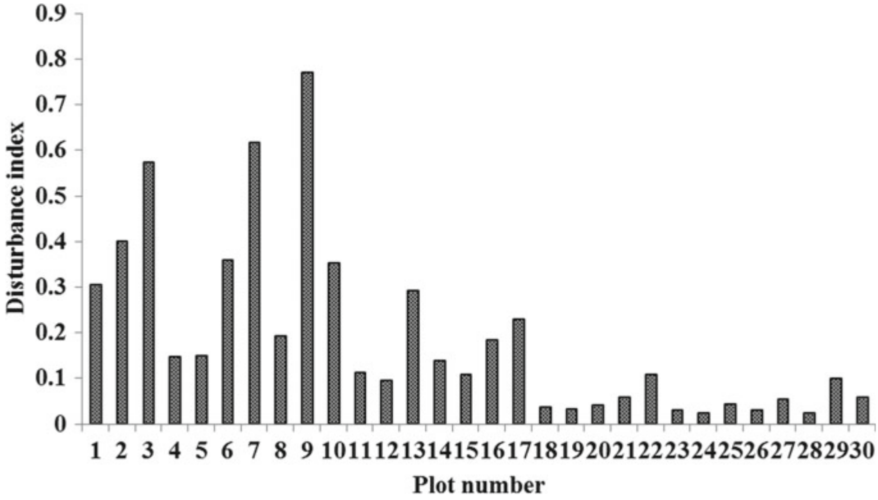

Fig. 9 Disturbance index of the study plots in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats

3.6 Distribution Pattern

The A/F ratio of species in plots indicates the species distribution patterns. Overall, 93.83% of species (of all life forms—trees, shrubs, herbs and climbers) showed contagious distribution, 5.31% showed a random distribution and 0.86% showed the regular distribution (Fig. 9). In tree community, 91.55% showed contiguous distribution, 8.27% showed random and 0.18% showed regular distribution patterns. In shrub community, 81.68% of shrub species showed the contiguous distribution while 13.55% showed random and 4.76% showed regular distribution patterns. Similarly, contiguous distribution was more common in herb (98.89%) and climber (97.02%) life forms.

4 Discussion

The plant species richness recorded from 30 (1 ha) plots in the tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats was 210, of which, trees and herbs occupied a significant proportion (35.71% species each) followed by lianas (15.71%) and shrubs (12.86%). The observed species richness in the present study plots (35–84 species/ha) is greater than those reported in a tropical dry deciduous forest of northern Eastern Ghats (18–55 species/ha; Devi and Behera 2003) and in line with the findings of Reddy et al. (2008a, b) and elsewhere (Hubbel 1979; Jimenez et al. 2016). However, total species richness encountered in this study is much lower than those values (173–218 species/ha) reported by Reddy et al. (2011) from tropical moist deciduous forests of Eastern Ghats, Andhra Pradesh. Plant diversity is directly influenced by many factors including climate, topography, soil and natural/anthropogenic causes (Behera et al. 2016). All the 30 one-hectare study plots of Sathanur reserve forest are located within the radius of 10 km and an altitude ranging from 192 to 250 m, hence, the climate cum topography of study plots largely remain the same. The human disturbance varied considerably among the study plots due to closeness to the settlement, agricultural field and rivulet, roads and path intrusions. The plots located near to rivulet have more soil moisture and air humidity due to water flow. The plots laid along roadsides and near human settlements are subjected to anthropogenic pressure which has resulted in an increase in cut stems. Seepage from the agricultural land to forest area also increases soil moisture content in the study plots which are close to them. These microclimatic variations among the plots could be the reason for the significant spatial variation in species richness and density among the plots even though they are located within 10 km radius. The low species richness recorded in the present study compared to the Western Ghats and some regions of Eastern Ghats could be ascribed to low and erratic rainfall pattern, anthropogenic disturbances and extensive grazing.

Tree species richness is vital to tropical forest biodiversity because trees directly or indirectly support almost all other life forms (Huston 1994). Tree (for individuals $\geq$10 cm DBH) species richness recorded in the current study plots ranged 7–28 species/ha, which is much lower than previous studies conducted in other parts of Eastern Ghats, for example, Kadavul and Parthasarathy (1999a, b) reported 42 to 47 species/ha in Kalrayan hills and 33–50 species/ha in Shervarayan hills. Similarly, Chittibabu and Parthasarathy (2000a) encountered 26–54 species/ha in Kolli hills of Eastern Ghats. Reddy et al. (2008a) reported 60–69 species/ha in dry deciduous forests of Eastern Ghats. Premavani et al. (2014) estimated 34–48 species/ha in tropical dry forests of central Eastern Ghats. The relatively lower species richness values obtained in the present study when compared to the other studies (Palomino and Alvarez 2008; Powers et al. 2009; Rao et al. 2015; Naidu and Kumar 2016; Sahoo et al. 2017) could be attributed to the greater extent of anthropogenic activities prevailing in the study plots including stem cutting and stem removal in addition to low rainfall.

The species richness of climbers registered in this study (3–23 species/0.125 ha) is comparable to other areas of Eastern Ghats i.e., Kolli hills (2–17 species/ha; Chittibabu and Parthasarathy 2001), tropical dry deciduous forest of Srilankamalla wildlife sanctuary, Andhra Pradesh (6–27 species/ha; Mastan et al. 2015). However, the value obtained in the present study is lower than in tropical dry deciduous forest of Nallamalai–Seshachalam–Nigidi hills of Eastern Ghats (21–29 species/ha; Reddy et al. 2008a), in the Vindhyan tropical dry deciduous forest (37 species/ha; Sharma and Raghubanshi 2010) and in Mudumalai Wildlife Sanctuary, southern India (53 species/ha; Joseph et al. 2008). The species richness of climbers is comparable even though this study site has low species richness (includes all life forms) in general which could be attributed to anthropogenic perturbation as observed by Dewalt et al. (2000), Laurance et al. (2001) and Schnitzer and Bongers (2002). According to Gerwing and Uhl (2002) and Schnitzer et al. (2004), human activities including logging create canopy gaps, which lead to more light exposure that subsequently results in the successful establishment of climbers and lianas.

The density of climbers enumerated in the present study was 569.6 individuals/ha (range: 9–252 individuals/0.125 ha). This value is comparable with other reports from tropical forest of Eastern Ghats such as Kolli hills (12.5–56 individuals/ha; Chittibabu and Parthasarathy 2001) and Bobiri forest reserve, Ghana (152–280 individuals/ha; Addo-Fordjour et al. 2009). The wide variations in the climber density among plots could be due to different levels of anthropogenic pressures associated with canopy opening and other microclimatic conditions. The low density of climbers in few plots observed in the present study may be due to selective tree felling as stated by Chittibabu and Parthasarathy (2000b).

Species richness of understory vegetation in 30 one-hectare plots in the tropical dry deciduous forest of Sathanur reserve forest was 102 (fifty 25 m^2 quadrats for shrubs and fifty 1 m^2 quadrats for herbs in each one-hectare plot). Comparatively, the value obtained in the present study is moderately higher than the other parts of Eastern Ghats and elsewhere (52 species/0.32 ha (eight hundred 4 m^2 quadrats) in tropical evergreen forest in the Kolli hills, Chittibabu and Parthasarathy (2000b); 84 species/4 ha in tropical dry deciduous forest in Odisha, Sahu et al. (2007); 32–93 species/0.05 ha (twenty 25 m^2 quadrats) in riparian environments of Atlantic forests in Rernambuco, Brazil, Gomes-Westphalen et al. (2012)). However, this is lower than several reports of tropical forests in India (155 species/1.2 ha (three thousand 4 m^2 quadrats in 30 ha plots) in tropical evergreen forest in Anamalais, Western Ghats, Annaselvam and Parthasarathy 1999; 170 species/3 ha (shrubs + herbs) in tropical dry deciduous forest in Nallamalai-Seshachalam-Nigidi hills of Eastern Ghats, Andhra Pradesh, Reddy et al. 2008a; 107 species/2.04 ha (shrubs + herbs) in tropical dry deciduous forest in Similipal biosphere reserve, Odisha, Reddy et al. 2008b; 269 species in tropical forest tract of Sileur-Maredumilli hills of north Eastern Ghats, Reddy et al. 2011). The wide variations in understory species richness may be influenced by various ecosystem processes like nutrient cycling, decomposition of organic matter, hydrological cycle, soil formation, species composition of overstory, canopy cover, light penetration, different levels of disturbances, etc., as suggested by Singh et al. (2014). Comparison of understory diversity is very difficult because of the variations in the area of sampling, size of quadrats, number of quadrats etc. as suggested by Chittibabu and Parthasarathy (2000a, b). However, the value recorded in the present study is well within the range (Annaselvam and Parthasarathy 1999). The population density of understory species (shrubs and herbs) varied considerably among the species as well as among the plots. In shrub community, the three dominant species occupy 81% of populations. *Lantana camara* population contributed 32% of shrub composition. In the herbaceous community, five dominant species were represented by 62,318 individuals (57%) in all the study sites. In the herbaceous community, annuals were more predominant than that of perennials. Similarly, annuals were more predominant in the herbaceous community in tropical evergreen forests of Anamalais, Western Ghats as observed by Annaselvam and Parthasarathy (1999). In contrast, perennials dominated the understory community in Amazonian rainforest (Poulsen and Balslev 1991). The prevalence of annuals in the herbaceous community as observed in this study could be largely due to seasonal variation i.e. hot summer (herbaceous vegetation is completely dried off and rejuvenate in rainy season) and overgrazing. The shrub species richness is low in few study plots, owing to tree species dominance. The presence of *Lantana camara*, an alien weed, in all the studied plots indicates that it would have probably invaded the Sathanur reserve forest several years back and had successfully established itself (Behera and Misra 2006). The low density of herbaceous vegetation in the inner plots is because of low insulation on the forest floor as the canopy is closed.

The species diversity is dependent on the capability of species to adapt, which increases as the community becomes more stable. Species diversity is brought about by species interaction like competition as well as niche variation (Pianka 1966), which are prominently expressed in the tropical regions because of high temperature and humidity (Ojo and Ola-Adams 1996). Shannon's index is generally higher for tropical forests (Knight 1975), whereas in Indian forests, the reported range was 0.83–4.1 (Singh et al. 1981; Sundarapandian 1997). In the present study, Shannon's index value ranged from 0.716–2.343 for tree species; 0.812–1.948 for shrubs; 1.157–2.8 for herbs and 0.243–2.796 for climbers. It is very difficult to compare diversity indices due to variations in the sampling location and uneven plot dimensions. The greater dominance index could be due to the mono-species dominance exhibited by *Albizia amara* in this forest ecosystem.

The density of species is directly dependent on species richness (Denslow 1995; Condit et al. 1998). The extent of tree density contributes as much to the forest's functional diversity, ecological processes and ecosystem services (Gopalakrishna et al. 2015). The mean tree density of 584 stems/ha registered in the present study is closer to the Amazonian average (597 stems/ha; Lewis et al. 2004) and Bornean (Asia) average (602 stems/ha; Slik et al. 2010), and 28.8% higher than the tropical forest average (425 stems/ha; Lewis et al. 2013) of Africa. Similarly, the value recorded in the present study is in line with those reported by Pragasan and Parthasarathy (2010) in the southern Eastern Ghats (457 stems/ha); Reddy et al. (2008b) in Similipal biosphere reserve (568 stems/ha) and Sahu et al. (2007) who reported 591 stems/ha in tropical dry deciduous forest, Odisha. However, the mean tree stem density values in the present study are lower than the findings of Kadavul and Parthasarathy (1999a, b) who reported 815 stems/ha in Shervarayan hills of southern Eastern Ghats. Similarly, Reddy et al. (2008a, 2011) reported 735 stems/ha and 709 stems/ha respectively in the tropical dry deciduous forest, Andhra Pradesh. The observed tree species density in the present study is higher than the findings of Sahu et al. (2012), Premavani et al. (2014), and Sahu et al. (2016) with 443 stems/ha, 360–526 stems/ha and 479 stems/ha respectively in the northern Eastern Ghats. Similarly, low stand density was recorded from other tropical forests of the world: Brazil (420–777 stems/ha; Campbell et al. 1992), Costa Rica (448–617 stems/ha; Heaney and Proctor 1990) and Malaysia (250–500 stems/ha; Primack and Hall 1992). Therefore, the observed density of trees in the present study can be considered modest when compared to the similar forest types in the Indian Eastern Ghats. Tree density may be influenced by anthropogenic activities and soil properties.

Top ten tree species including *Albizia amara* and *Chloroxylon swietenia* dominated the entire stand, contributing to 90.01% of the total individuals. Tree density differences among the plots could be due to the efficiency of seed dispersal and its establishment as well as resource exploitation levels by locals as suggested by Kadavul and Parthasarathy (1999a). Nevertheless, mono-dominance of species like *Albizia amara* in all the study plots shows their inherent ability to thrive in varied environmental conditions and in disturbed areas.

The mean basal area of tree community was 18.71 m^2/ha in dry deciduous forests of Sathanur reserve forest that is modest when compared to the dry tropical forest in Vindhyan hills (Jha and Singh 1990). The value (7.22–43.05 m^2/ha) obtained in the present study is well within the range of tropical dry forests in other parts of India (range 7–23.2 m^2/ha, Jha and Singh 1990; mean 29.0 m^2/ha, Reddy and Ugle 2008; range 8.15–41.17 m^2/ha, Sahu et al. 2008; range 8.6–26.9 m^2/ha, Reddy et al. 2008a; range 30–39 m^2/ha, Reddy et al. 2011; 6.86 m^2/ha, Sahu et al. 2012; range 12.98–33.3 m^2/ha with mean of 25.82 m^2/ha, Naidu and Kumar 2016) and elsewhere (Murphy and Lugo 1986; Lieberman and Lieberman 1987; Campbell et al. 1992). However, our mean value is less than the pantropical mean of 32 m^2/ha (Dawkins 1959), Amazonian average (29 m^2/ha; Lewis et al. 2004), Bornean (Asia) average (37.1 m^2/ha; Slik et al. 2010), African average (31.5 m^2/ha; Lewis et al. 2013) and other forests of Eastern Ghats (Kadavul and Parthasarathy 1999a, b). Similarly, the mean value recorded in the present study is lower than mean basal area values reported by several others in tropical forests of Western Ghats (Singh et al. 1981; Sundarapandian and Swamy 2000). The wide variations in the basal area among the 30 one-hectare plots obtained in the present study indicate that these plots were subjected to different levels of anthropogenic pressure. Exceptionally few plots have high values of the basal area, which indicates that those plots have more mature trees whereas, in some plots that had low basal area, there were many juveniles and very few mature trees. This is probably due to greater biotic disturbances in the area as suggested by Thakur (2015).

A total of 63 families were observed in this tropical dry deciduous forest. The most speciose families are Euphorbiaceae and Poaceae, followed by Fabaceae and Rubiaceae. Interestingly, similar findings were reported by Pragasan and Parthasarathy (2010) in tropical deciduous forests of the Eastern Ghats, where Euphorbiaceae, Rubiaceae and Moraceae were the most dominant families. Borah et al. (2016) also found that Euphorbiaceae was the dominant family in tropical forests of Barak Valley, Assam. Several others also observed the similar results (Ifo et al. 2016; Naidu and Kumar 2016). Hence, it can be noted that there is a similarity in family composition of forests in tropical environments.

Diameter class frequency exhibited an L-shaped curve for the trees and the data is in line with many other reports from Eastern and Western Ghats (Sundarapandian 1997; Kadavul and Parthasarathy 1999a). This is the typical characteristic of a tropical forest. The DBH size class distribution showed a decline in the number of individuals from lower class to higher class, indicating expanding population. The stem density decreased with increase in diameter class of trees as observed in the present study, which is in agreement with other reports (Lieberman et al. 1985; Swaine et al. 1987;

Campbell et al. 1992; Swamy et al. 2000; Sundarapandian and Karoor 2013). This type of distribution indicates that this forest has a good potential for regeneration. Species richness also decreased with increase in diameter class. A similar trend was exhibited by the dominant species. Greater proportion (81.9%) of stems belonged to lower diameter class (≥3.2 cm −<10 cm). This is so because of growth of coppices from illegal cutting of adult stems for firewood and domestic purposes. This is the same case with many other dry forests where lower diameter class individuals are more in number. The greater density of low diameter class individuals is primarily due to open canopy (Manokaran and La Frankie 1990).

A/F ratios indicate species distribution patterns in a community. According to Odum (1971), generally, contagious distribution is the most common pattern in nature; while random distribution is restricted to very homogeneous microclimates and regular distribution prevails where competition among the population exists. Species distribution patterns vary due to differences in microclimate, habitat heterogeneity, dispersal ability and allelopathy (Kandari et al. 2011). Understanding the distribution patterns would be useful to develop management strategies in these forests that are under pressure.

Human activities and cattle grazing in forest ecosystems have changed the diversity, structure and functions of ecosystems (Sundarapandian and Swamy 2000; Swamy et al. 2000; Sundarapandian and Karoor 2013; Sundarapandian et al. 2015). The effect of anthropogenic disturbances on forest features would be plot-specific (Htun et al. 2011). Some plots (plot nos. 1–10) in the present study are near roads, human settlements or the agricultural fields which are easily accessible to human exploitation. The tree species richness was found to be low in these plots (plot nos. 1–10 except for 1, 7 and 10) compared to other study plots while shrub and herb species richness are observed to be more in these plots. The lower number of tree species may be due to several kinds of anthropogenic perturbations. Although the study area is a reserve forest, localites frequently cut trees and collect firewood, lop branches and graze their cattle. Illegal selective cutting of *Chloroxylon swietenia* for fencing, agricultural tools and other domestic purposes and *Albizia amara* for firewood are quite frequent in this forest. This kind of selective cutting may result in coppicing of those species which could affect forest species composition and stand structure. This has resulted in more density of both species in the plots near to the road, agriculture field and settlements which enhance the tree density in these plots. Due to greater tree density in these plots, the density of the herbaceous community is comparatively low here. Study plots (plot no. 21–30) are located on both sides of the rivulet. In general, the plots near the rivulet also have lower species richness; this could also be attributed to human disturbance and edaphic factors. The study area has a rocky terrain that would alter the structure of the forests. People regularly use the rivulet for day to day activities. In addition to that, this is a source of drinking water for cattle and hence, these plots were also under high anthropogenic pressures. The present study reveals that the edaphic variations and anthropogenic disturbance alter the microclimate among the plots which could be the reason for the significant spatial variation in species richness and density among the plots even though they are located within 10 km radius.

Anthropogenic perturbation in tropical dry deciduous forests of Sathanur Reserve forests creates niche space for ruderal weeds and alien invasive species to colonize and establish. Ruderal weeds and alien invasive species were the dominant understory community in all the study plots. Herbaceous community population in the study plots were dominated by native ruderal species like *Sida cordifolia*, *Sida cordata* and *Sida acuta*. Generally, these native ruderal species occur abundantly in the first year of the fallow-land of agroecosystems, wastelands subjected to frequent disturbances, adjacent to roads and rivulet, and moderately shaded and open areas of forests. The greater density of these ruderal weeds implied that these study plots are still under a certain level of disturbance. Alien invasive plants, *Lantana camara* and *Ageratum conyzoides* were observed in 100% and 93% of plots respectively. In addition to that, another exotic invasive species *Prosopis juliflora* was also registered in 43% of plots. This successful colonization and establishment of alien invasion revealed that these study plots are either under disturbance or have canopy opening. Many studies have confirmed that the natural or anthropogenic perturbations pave way for a conducive environment for the establishment of invasive plants (Whitmore and Burslem 1996; Sundarapandian 1997; Sundarapandian and Karoor 2013). In shrub community, 32.18% of the population is contributed by exotic invasive species. Similarly, in the herbaceous community, exotic invasive species contribution is 13.33%. The present study reveals that the understory vegetation of tropical dry deciduous forest at Sathanur Reserve forest is dominated by ruderal weeds and exotics. It indicates that this forest is under the threat of anthropogenic pressure even though it has been declared as a reserve forest. However, this forest ecosystem restores rich flora similar to other tropical dry forests of the Eastern Ghats and central India. To impede the plant invasion, timely measures are to be adopted to eliminate invasive species in order to retain and conserve the native diversity.

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Herpetofaunal Diversity and Conservation Status in Amchang Wildlife Sanctuary of Assam, India

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Abstract A bio-inventory of herpetofauna occurring in Amchang wildlife sanctuary was made along with identification of perceived threats, the herpetofauna faces in the sanctuary. During the study period 22 species of amphibians representing seven families and 41 species of reptiles representing eleven families were encountered. According to conservation concern based on categorization by IUCN redlist, amongst amphibians a single species was vulnerable, four species were data deficient and the rest were least concern and amongst reptiles, two species were vulnerable, 13 species were least concern and the rest of 26 species were yet to be evaluated. According to India's Wildlife (Protection) Act, 1972, 13 species of amphibians fall under Schedule IV; five, three and twenty species of reptile come under Schedule I, schedule II and Schedule III respectively. The remaining species are non-scheduled. The major threats in the sanctuary includes habitat degradation, encroachment of forest land and lack of people awareness regarding herpetofauna.

Keywords Herpetofauna · Amphibians · Reptiles · Amchang Wildlife Sanctuary · Guwahati

1 Introduction

Amchang Wildlife Sanctuary (Fig. 1) is situated at the eastern border of Guwahati city between 91°49′54.46″ E to 91°59′31.93″ E and 26°6′22.14″ N to 26°14′46.07″ N with elevation varying from 54 to 545 m ASL. The area of the sanctuary is about 78.64 km^2 which comprises Amchang Reserve Forest (53.18 km^2), Khanapara Reserve Forest

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Fig. 1 A map showing topography of Amchang Wildlife Sanctuary. Inset: map of India with red dot pointing to the Amchang wildlife sanctuary

(09.96 km^2) and South Amchang Reserve Forest (15.50 km^2). The main vegetation type is semi-evergreen and mixed deciduous forest, along with open grassland and agricultural fields. Small water bodies and hill streams can be found throughout the sanctuary. Dams can also be seen within the sanctuary. So far 301 species of vascular plants (Kar et al. 2015), 72 species of butterflies (Ahmed and Das 2016) and 38 species of mammals (Sharma et al. 2013) were recorded from this sanctuary. In this chapter we present a bio-inventory of herpetofauna occurring in Amchang Wildlife Sanctuary along with perceived threats.

2 Materials and Methods

The study was conducted between September 2013 and August 2015. A total of 92 surveys were conducted with 9 man hour invested survey. A large portion of the survey were conducted between April to October (68 surveys). Since the main goal of the study was to create a checklist visual encounter survey (Crump and Scott 1994) employing randomized walk (Lambert 1984) was employed along with active search (Rolfe and McKenzie 2000). The herpetofauna encountered were photographed and identified using literature (Smith 1931, 1935, 1943; Ahmed et al. 2009; Purkayastha 2013) before releasing them back.

3 Results and Discussion

During the study period 22 species of amphibians representing seven families and 41 species of reptiles representing eleven families were encountered (Table 1). According to conservation concern based on categorization by IUCN redlist, amongst amphibians a single species was vulnerable, four species were data deficient and the rest were least concern and amongst reptiles, two species were vulnerable, 13 species were least concern and the rest of 26 species were yet to be evaluated. According to India's Wildlife (Protection) Act, 1972, 13 species of amphibians fall under Schedule IV; five, three and twenty species of reptiles come under Schedule I, Schedule II and Schedule III respectively. The remaining species are non-scheduled.

Amongst amphibians *Duttaphrynus melanostictus* (Schneider 1799), *Euphlyctis cyanophlyctis* (Schneider 1799), *Fejervarya teraiensis* (Dubois 1984), *Fejervarya nepalensis* (Dubois 1975), *Polypedates teraiensis* (Dubois 1987) were found to be common species. *Duttaphrynus melanostictus*, however was mostly restricted to the forest edges with decreased sighting rates as we move to the core of the forest. We have encountered *Ichthyophis* only four times in the entire study period. Amongst reptiles *Calotes versicolor* (Daudin 1802), *Hemidactylus frenatus* (Dumerili and Bibron 1836), *Hemidactylus platyurus* (Schneider 1792), *Sphenomorphus maculatus* (Blyth 1853), *Lycodon aulicus* (Linnaeus 1758), *Xenochrophis piscator* (Schneider 1799) were found to be common species. Turtles were only encountered for six times during the entire survey.

Secondary data suggests that there is a rapid decline in the vegetation cover and biodiversity within the study area. This is supported by the data of a comparative survey on change of land use pattern in 1989 and 2011 showing that dense forest has increased from 1428.37 to 1619.13 ha where as moderate dense forest has drastically reduced from 2530.18 to 1256.1 ha (Changkakati 2017). A large part of area under moderate dense forest were used up for developmental activates such as for stone quarries, agriculture, plantations, construction of dams. The study area and its periphery are inhabited by ethnic (mainly Karbi) groups of Assam and Nepali population. The main mode of subsistence is agriculture and dairy production. Rice is the main cultivated crop along with betel nut plantation. There also exist patches of bamboo and Sal tree plantation. Fishing is practiced in ponds and small hill streams. In fact there are many settlements which are within the Amchang Wildlife Sanctuary and its adjourning eco-sensitive zone. In year 2017, a massive eviction drive was undertaken and over 700 families were ousted from the area, which led to mass protest. About 50% of the herpetofauna (30 species out of 63) in the study area are either not evaluated (26 species) or under data deficient (4 species) category of IUCN redlist pointing to the fact that more species specific study is to be undertaken to evaluate the conservation status of each species.

Major threats to herpetofauna observed in the study area are as given below.

Habitat degradation and alteration: Many of the moderate dense forests and secondary forests are now replaced by agricultural fields and monotypic cultivation, predominated by Sal plantation. Hills are exploited for soil, rock and timbers ever

Table 1 A checklist of herpetofauna of Amchang Wildlife Sanctuary along with their conservation and legal status

Taxon	Scientific name	IUCN redlist	IWPA schedule
Class—Amphibia			
Bufonidae	*Duttaphrynus melanostictus* (Schneider 1799)	LC	NS
Megophryidae	*Megophrys parva* (Boulenger 1893)	LC	NS
Microhylidae	*Microhyla ornata* (Dumerili and Bibron 1841)	LC	NS
	Microhyla berdmorei (Blyth 1856)	LC	NS
Dicroglossidae	*Hoplobatrachus tigerinus* (Daudin 1803)	LC	IV
	Euphlyctis cyanophlyctis (Schneider 1799)	LC	IV
	Fejervarya teraiensis (Dubois 1984)	LC	IV
	Fejervarya pierrei (Dubois 1975)	LC	IV
	Fejervarya syhadrensis (Annandale 1919)	LC	IV
	Fejervarya nepalensis (Dubois 1975)	LC	IV
	Limnonectes khasianus (Anderson 1871)	DD	IV
Ranidae	*Amolops assamensis* Sengupta et al. 2007	DD	IV
	Amolops gerbillus (Annandale 1912)	LC	IV
	Humerana humeralis (Boulenger 1887)	LC	IV
	Silvirana leptoglossa (Cope 1868)	LC	IV
	Clinotarsus alticola (Boulenger 1882)	LC	IV
	Hylarana tytleri (Theobald 1868)	LC	IV
Rhacophoridae	*Polypedates teraiensis* (Dubois 1987)	LC	NS
	Philautus garo (Boulenger 1919)	VU	NS
	Rhacophorus bipunctatus Ahl 1927	LC	NS
Ichthyophiidae	*Ichthyophis garoensis* (Pillai and Ravichandran 1999)	DD	NS
	Ichthyophis moustakius Kamei et al. 2009	DD	NS
Class—Reptilia			
Tryonichidae	*Nilssonia hurum* (Gray 1831)	VU	I
	Lissemys punctata (Bonnaterre 1789)	LC	I

(continued)

Table 1 (continued)

Taxon	Scientific name	IUCN redlist	IWPA schedule
Bataguridae	*Pangshura tentoria*(Gray 1834)	LC	NS
Agamidae	*Calotes versicolor* (Daudin 1802)	NE	NS
	Ptyctolaemus gularis (Berlin 1864)	NE	NS
Gekkonidae	*Hemidactylus frenatus* (Dumerili and Bibron 1836)	LC	NS
	Hemidactylus brookii (Gray 1845)	NE	NS
	Hemidactylus platyurus (Schneider 1792)	NE	NS
	Hemidactylus aquilonius Zug and McMahan 2007	NE	NS
	Cyrtodactylus khasiensis (Jerdon 1870)	NE	NS
	Cnemaspis assamensis (Das and Sengupta 2000)	NE	NS
	Gekko gecko (Linnaeus 1758)	NE	IV
Scincidae	*Eutropis multifasciata* (Kuhl 1820)	NE	NS
	Eutropis macularia (Blyth 1853)	NE	NS
	Sphenomorphus maculatus (Blyth 1853)	NE	NS
	Lygosoma albopunctatum (Gray 1846)	NE	NS
Varanidae	*Varanus bengalensis* (Daudin 1802)	LC	I
	Varanus flavescens (Hardwicke and Gray 1827)	LC	I
Typhlopidae	*Indotyphlops braminus* (Daudin 1803)	NE	IV
	Argyrophis diardii (Schlegal 1839)	LC	IV
Boidae	*Python bivittatus* (Kuhl 1820)	VU	I
Colubridae	*Dendrelaphis proarchos* (Wall 1909)	NE	IV
	Ahaetulla nasuta (Lacepede 1789)	NE	IV
	Lycodon aulicus (Linnaeus 1758)	NE	IV
	Lycodon zawi Slowinski et al. 2001	LC	IV
	Oligodon albocinctus (Cantor 1839)	NE	IV
	Boiga gokool (Gray 1834)	NE	IV
	Boiga cyanea (Duméril et al. 1854)	NE	IV
	Coelognathus radiatus (Boie 1827)	LC	IV
	Coelognathus helena (Daudin 1803)	NE	IV

(continued)

Table 1 (continued)

Taxon	Scientific name	IUCN redlist	IWPA schedule
	Xenochrophis piscator (Schneider 1799)	NE	II
	Amphiesma stolata (Linnaeus 1758)	NE	IV
	Enhydris enhydris (Schneider 1799)	LC	IV
	Ptyas mucosa (Linnaeus 1758)	NE	II
	Ptyas korros (Schlegel 1837)	NE	IV
	Rhabdophis subminiatus (Schlegel 1837)	LC	IV
	Chrysopelea ornata (Shaw 1802)	NE	IV
	Psammodynastes pulverulentus (Boie 1827)	NE	IV
Elapidae	*Naja kaouthia* (Lesson 1831)	LC	II
	Bungarus fasciatus (Schneider 1801)	LC	IV
Viperidae	*Trimeresurus albolabris* Gray 1842	LC	IV

increasing the threat of a major landslide. Many of the water bodies within the study are extensively used for fishing which many times results in engagement of snakes (*Xenochrophis piscator*) to the fishing nets resulting in death.

Encroachment: Guwahati city is the biggest metropolis of northeast India. People not only from Assam but also from different northeastern states move to Guwahati for a better life. Most of these fall under low income group and settle in the city's fringe areas where cost of living is low. Amchang being close to Guwahati, has to bear the burden of such immigration settlement often resulting in encroachment of forest land. Of the total area 7.7 km^2 are under encroachment, including settlements that had been there prior to its upgradation to a sanctuary in 2004 (Changkakati 2017).

Lack of awareness: People in and around the study area were seen to have lots of misinformation and superstition related to herpetofauna. Most of the human-snake encounter in the study area results in the death of the snake. *Hoplobatrachus tigerinus*, *Amolops assamensis*, *Lissemys punctata*, *Varanus bengalensis* were locally consumed in the study area.

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A Preliminary Checklist of Herpetofauna Occurring in Rowa Wildlife Sanctuary, Tripura, India

Jayaditya Purkayastha, Nazruddin Khan and Shubhadeep Roychoudhury

Abstract Rowa wildlife sanctuary is the smallest of the four wildlife sanctuaries of Tripura comprising of an area of 0.860 km^2. In this study we recorded 20 species of amphibians representing 6 families and 33 species of reptiles representing 9 families. One of the amphibian species namely *Hoplobatrachus litoralis* is a first record from India. During the survey we encountered open turtle trade being conducted in the markets of Agartala. The prime species involved in the flesh trade are *Nilssonia hurum* and *Lissemys punctata andersoni*. Both the species are under Schedule I of Indian Wildlife (Protection) Act, 1972.

Keywords Rowa · Tripura · India · Herpetofauna · Reptiles · Amphibians

1 Introduction

The state of Tripura occupies a geographic area of 10,486 km^2 occupying about 0.31% of India's geographic area. According to Government assessment (OGD 2011), the state had 7977 km^2 of forest cover (very dense forest: 109 km^2, moderately dense forest: 4686 km^2, open forest: 3182 km^2). According to the data of state forest department Tripura has 1545 species of plants, 90 species of mammals, 342 species of birds (TFD 2016), but no data exists on the herpetofauna of the state. Being a part of Indo-Burma biodiversity hotspot, with a forest type comprising of tropical evergreen, semi evergreen, moist deciduous and a tropical savanna climate, 77.94 to 108.11 in average annual rainfall, with summer temperature ranging from 24 to 36 °C and winter 13 to 27 °C (TFD 2016), makes the state conducive for herpetofaunal assemblage. Rowa Wildlife Sanctuary is situated in North Tripura and is by far the smallest Wildlife Sanctuary of the state with an area of 0.860 km^2. A recent study on butterfly fauna of the sanctuary resulted in listing of 53 species belonging to

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Fig. 1 Left: a map of Rowa Wildlife Sanctuary. Right: a map of Tripura (red overlay) pointing Rowa Wildlife Sanctuary (solid red dot)

36 genera and 5 families (Lodh and Agarwala 2016). In this chapter, we provide a preliminary checklist of herpetofauna occurring in Rowa Wildlife Sanctuary.

2 Materials and Methods

2.1 Study Site

Rowa Wildlife Sanctuary (Fig. 1) is situated in North Tripura (24°17′34.00″ N, 92°9′59.45″ E) with in an area of 0.860 km^2. The chief habitat types are regenerated secondary forest, a botanical garden and bamboo bush, with perennial water bodies. In and around the sanctuary there are settlements of indigenous communities. The forest mostly comprises of moist deciduous type.

2.2 Data Collection

The study was conducted between 9 August 2016 and 14 September 2016. For sampling, we conducted visual encounter survey (Crump and Scott 1994) along with active search. Visual encounter survey was based on randomised walk, investing 240 man hour for the entire survey. We carried out survey for 20 days comprising of 3 individuals per survey with an investment of 4 h per survey. We have also taken into account the specimen killed by the locals comprising mostly of snakes. All of the recorded animals were photographed and released. Identification of the specimens were done following Ahmed et al. (2009) and Purkayastha (2013).

3 Results

During the study we found 20 species of amphibians representing 6 families and 33 species of reptiles representing 9 families (Table 1; Figs. 2, 3 and 4). Amongst amphibians, family Dicroglossidae was found to be the most species rich with a good population size for each species. *Minervarya teraiensis* (Dubois 1984) was found to be the most abundant of amphibians in the study site. Though Bufonidae has a single species represented by *Duttaphrynus melanostictus* (Schneider 1799), it is the second most abundant amphibian. Amongst lizards family Gekkonidae was the most species rich represented by 6 species. *Varanus bengalensis* (Daudin 1802) was the biggest of all the lizards and was reported to be eaten by the local tribe. Colubrid snakes are the most species rich snake in the study site with *Dendrelaphis proarchos* Wall 1909 being the most common one. The most important finding of this study was a dicroglossidae frog, *Hoplobatrachus litoralis* (Hasan et al. 2012). This is the first record of the frog from India (Purkayastha and Basak 2018).

Table 1 A systematic checklist of herpetofauna of Rowa Wildlife Sanctuary

Scientific name	Family
Class: Amphibia	
Duttaphrynus melanostictus (Schneider 1799)	Bufonidae
Leptobrachium smithi Matsui Nabhitabhata and Panha 1999	Megophryidae
Megophrys parva (Boulenger 1893)	Megophryidae
Kaloula pulchra Gray 1831	Microhylidae
Microhyla rubra (Jerdon 1854)	Microhylidae
Microhyla ornata (Duméril and Bibron 1841)	Microhylidae
Microhyla berdmorei (Blyth 1856)	Microhylidae
Hoplobatrachus tigerinus (Daudin 1802)	Dicroglossidae
Minervarya nepalensis (Dubois 1975)	Dicroglossidae
Minervarya pierrei (Dubois 1975)	Dicroglossidae
Minervarya syhadrensis (Annandale 1919)	Dicroglossidae
Minervarya teraiensis (Dubois 1984)	Dicroglossidae
Euphlyctis cyanophlyctis (Schneider 1799)	Dicroglossidae
Euphlyctis hexadactylus (Lesson 1834)	Dicroglossidae
Hydrophylax leptoglossa (Cope 1868)	Ranidae
Hylarana tytleri Theobald 1868	Ranidae
Chiromantis simus (Annandale 1915)	Rhacophoridae
Philautus sp.	Rhacophoridae
Polypedates teraiensis (Dubois 1987)	Rhacophoridae
Rhacophorus bipunctatus Ahl 1927	Rhacophoridae

(continued)

Table 1 (continued)

Scientific name	Family
Class: Reptilia	
Calotes versicolor (Daudin 1802)	Agamidae
Ptyctolaemus gularis (Peters 1864)	Agamidae
Japalura planidorsata Jerdon 1870	Agamidae
Gekko gecko (Linnaeus 1758)	Gekkonidae
Hemidactylus brookii Gray 1845	Gekkonidae
Hemidactylus frenatus Duméril and Bibron 1836	Gekkonidae
Hemidactylus platyurus (Schneider 1797)	Gekkonidae
Hemidactylus aquilonius Zug and Mcmahan 2007	Gekkonidae
Cyrtodactylus tripuraensis (Agar et al. 2018)	Gekkonidae
Eutropis multifasciata (Kuhl 1820)	Scincidae
Eutropis macularia (Blyth 1853)	Scincidae
Sphenomorphus maculatus (Blyth 1853)	Scincidae
Lygosoma albopunctata (Gray 1846)	Scincidae
Varanus bengalensis (Daudin 1802)	Varanidae
Indotyphlops braminus (Daudin 1803)	Typhlopidae
Argyrophis diardii (Schlegel 1839)	Typhlopidae
Python bivittatus Kuhl 1820	Pythonidae
Ptyas mucosa (Linnaeus 1758)	Colubridae
Amphiesma stolatum (Linnaeus 1758)	Colubridae
Ahaetulla prasina (Boie 1827)	Colubridae
Rhabdophis subminiatus (Schlegel 1837)	Colubridae
Xenochrophis piscator (Schneider 1799)	Colubridae
Coelognathus radiatus (Boie 1827)	Colubridae
Dendrelaphis proarchos Wall 1909	Colubridae
Oligodon albocinctus (Cantor 1839)	
Psammodynastes pulverulentus (Boie 1827)	Colubridae
Lycodon aulicus (Linnaeus 1758)	Colubridae
Lycodon jara (Shaw 1802)	Colubridae
Chrysopelea ornata (Shaw 1802)	Colubridae
Boiga ochracea (Theobald 1868)	Colubridae
Bungarus fasciatus (Schneider 1801)	Elapidae
Naja kaouthia Lesson 1831	Elapidae
Trimeresurus erythrurus (Cantor 1839)	Viperidae

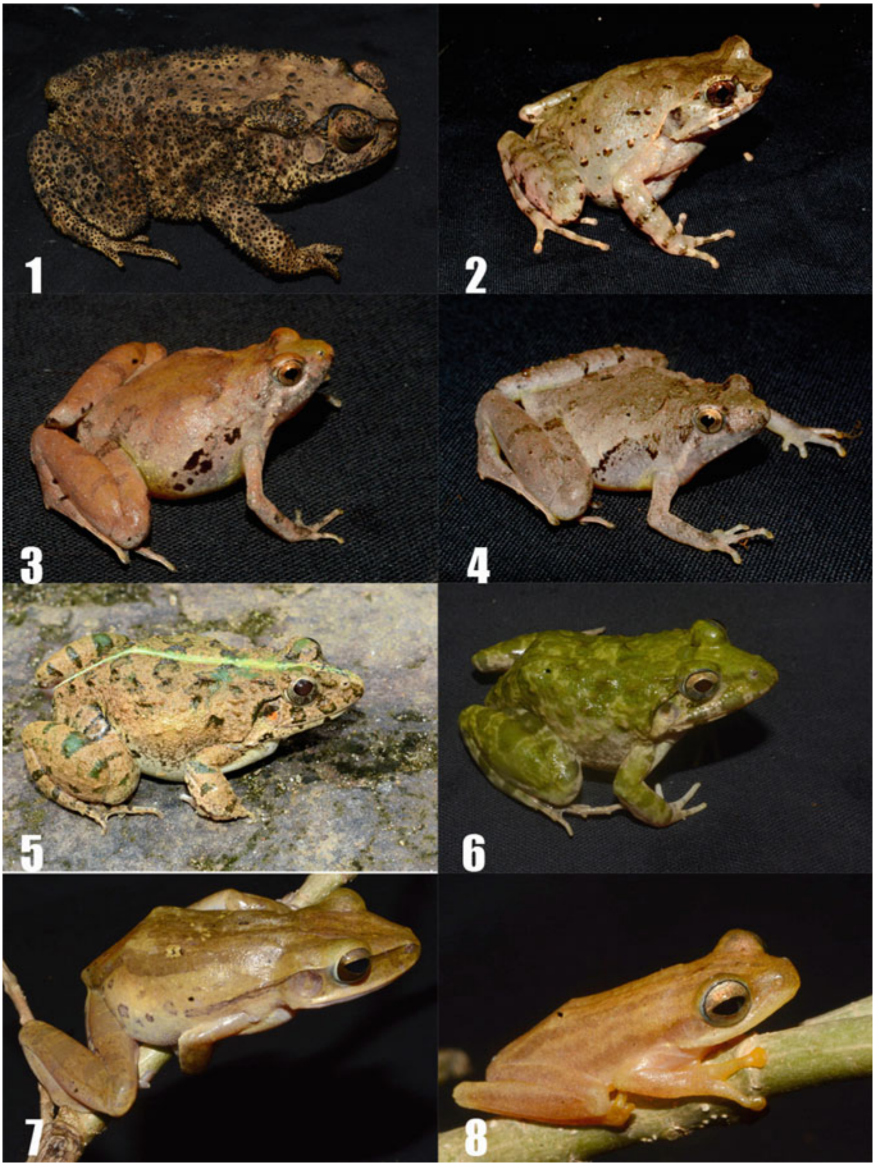

Fig. 2 Some amphibians of Rowa Wildlife Sanctuary (1: *Duttaphrynus melanostictus*, 2: *Megophrys parva*, 3: *Microhyla rubra*, 4: *Microhyla berdmorei*, 5: *Minervarya pierrei*, 6: *Minervarya teraiensis*, 7: *Polypedates teraiensis*, 8: *Chiromantis simus*)

Fig. 3 Some lizards of Rowa Wildlife Sanctuary (1: *Calotes versicolor*, 2: *Ptyctolaemus gularis*, 3: *Hemidactylus aquilonius*, 4: *Hemidactylus frenatus*, 5: *Gekko gecko*, 6: *Cyrtodactylus tripuraensis*, 7: *Eutropis multifasciata*, 8: *Lygosoma albopunctata*)

Fig. 4 Some snakes of Rowa Wildlife Sanctuary (1: *Argyrophis diardii*, 2: *Ahaetulla prasina*, 3: *Xenochrophis piscator*, 4: *Rhabdophis subminiatus*, 5: *Oligodon albocinctus*, 6: *Psammodynastes pulverulentus*, 7: *Bungarus fasciatus*, 8: *Trimeresurus erythrurus*)

4 Discussion

For most of Tripura, no organised data exists regarding its herpetofauna nor do we have assessment data on conservation status of its herpetofauna. Till date people of the state are oblivious of the provisions in Wildlife (Protection) Act, 1972 for protecting the fauna of the state. The capital city of Agartala still has a big market for turtle meat. In fish market of Gol Bazar and Battala bazar, turtle meat is sold in open without any restriction (Fig. 5). The prime turtle species involved are *Nilssonia hurum* (Gray, 1831) and *Lissemys punctata andersoni* (Webb 1980). It was informed that these turtles make their way to Tripura from Bangladesh. Manu, a village in Dhalai district of Tripura was also seen to have a market for turtle flesh. Local people were seen to be very much superstitious about snake and lots of myths still exists about snakes which makes conservation and conflict mitigation measures difficult to implement. During this short study period we recorded 11 individuals of snakes being killed by local people-five *Xenochrophis piscator* (Schneider 1799), three *Dendrelaphis proarchos*, two *Rhabdophis subminiatus* (Schlegel 1837) and a *Boiga ochracea* (Theobald 1868). The state still harbours a good forest cover, hence more research effort is needed in terms of its herpetofauna added upon by community awareness to secure the near future of herpetofauna of the state.

Fig. 5 Turtle meat being sold in Gol Bazar in Agartala, Tripura

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Biology, Uses and Conservation of *Trillium govanianum*

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Abstract *Trillium govanianum* is an endemic medicinal herb of the Himalayan region. Recently explored active constituents and their pharmacological activities from the species are of prime importance. Its range of distribution is highly specific in Indian Himalayas. Collection of its rhizome has become one of the significant commercial activity in the Indian Himalayas. However, the collection of the species is unsustainable. Understanding the socio-ecological dynamics of a species and carving out the prospects for its sustainable use is a difficult task in the Himalayas. Effective conservation strategies are needed to conserve the species while maintaining community incomes. The present chapter provides an overview of the biology, uses and conservation approaches that can be followed for the sustainable utilization of *T. govanianum* in Indian Himalayas.

Keywords Himalaya · Conservation · Medicinal plant · Threatened · Propagation · Trade

1 Introduction

Medicinal plants are used worldwide since the time immemorial for curing diseases and promoting health. More than 25% of the pharmaceutical industries of the world depend upon the natural plant products for synthesizing various drugs (Schmidt et al. 2008). The demand of the medicinal plants is mainly met through in situ harvesting which has resulted in the rapid depletion of the wild stocks. This widens the gap between demand and supply emphasizing on the sustainable utilization and conservation of the economically important medicinal plants. The Indian Himalayas are

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known to be bestowed with the rich diversity of medicinal plants. Diverse topographic, altitudinal and climatic features are responsible for a heterogeneous environment which corresponds to huge biodiversity in the Himalayas. It is a stake of more than 18,000 species of plants (Rana and Samant 2009), with more than 1700 having medicinal importance (Samant et al. 1998). The medicinal plants of the region fulfill most of the global demand of herbal industries (Dhar et al. 2000) irrespective of their rare occurrence, slow-growing nature, poor population density, endemism, narrow distribution range, and underdeveloped cultivation practices. Above scenario give space to illicit commercial harvesting practices pushing many species at the brink of extinction.

Among the medicinal plants, the members of the family, Melanthiaceae is recognized throughout the globe for their traditional and modern medicinal uses. The family Melanthiaceae comprises about 173 species, constituting 17 genera of flowering perennial herbs (Christenhusz and Byng 2016) which are mostly distributed in the temperate region of Northern Hemisphere (Zomlefer et al. 2001). *Trillium* is one amongst the large genera of the family Melanthiaceae comprising of 38 North American and 11 Asian species (Roskov et al. 2018). Two species of *Trillium* (*T. govanianum* and *T. tschonoskii*) are known from Indian Himalayan region. *T. govanianum* Wall ex D. Don (Melantiaceace) commonly known as Himalayan Trillium is endemic to the Himalayas (Samant et al. 1998; Kubota et al. 2006). The species has an important place in the Asian (China, India, Pakistan) folk medicine system (Zhan 1994; Shah 2006; Khan et al. 2016) as its rhizomes are known to contain several useful rare compounds, e.g. six steroidal saponins: govanoside A, borassoside E, pennogenin, diosgenin, 20-hydroxyecdysone, and 5,20-dihydroxyecdysone, of which govanoside A is known only in this species (Rahman et al. 2015b, 2017a). The species accumulates almost three-fold higher content of diosgenin (~6%) as compared to other explored medicinal plants (*Asparagus* spp., *Chlorophytum* spp., *Dioscorea* spp. and *Trigonella* spp.) (Singh et al. 2017). Diosgenin has multipurpose pharmaceutical uses; in fact, globally it is used as anti-cancerous, anti-ageing and the precursor for the synthesis of many steroidal drugs (Chaudhary et al. 2015).

Commercial collection of wild *T. govanianum* rhizomes has been observed from 2010 onwards, and its trade has emerged as a significant commercial activity in Himachal Pradesh and Uttarakhand (Ajuha 2013). Consequently, there is a concern that the overexploitation of the species has already led to local extinction, and could lead to extinction in the wild. Species is facing intense pressure in natural habitat and has gained tremendous popularity due to its medicinal and commercial importance.

2 Biology

2.1 Distribution

T. govanianum is distributed in the Himalayan range of Afghanistan, China (Tibet), Eastern & Western Himalayas (India), Nepal and Pakistan (Roskov et al. 2018). In Indian Himalayan Region, the species is found in the temperate and sub-alpine forest from Kashmir to Sikkim at an altitude of 2400–3500 m (Polunin and Stainton 1984; Hooker 1894). The species is more common in western Himalayan region as compared to eastern region (Chauhan et al. 2018). The main areas of its distribution in Uttarakhand are Munsiyari, Tungnath, Kedarnath, Pindari, Govind Pashu Vihar, Gangotri, Harshil, Panchachuli and Sunderdhunga. In Himachal Pradesh, the species is commonly reported from Kullu, Shimla, Kinnaur and Lahaul-Spiti while in Jammu and Kashmir, the species grows in Fatehpur, Gulmarg, Kanzalwan, Pahalgam, Poonch, Gurez, Sonamarg areas.

2.2 Morphology and Life Cycle

T. govanianum is a rhizomatous herb with a 10–20 cm tall stem. Leaves are broadly ovate, acute, stalked appearing in a whorl of three at maturity. At reproduction, usually, a single solitary flower of 2-3 cm emerges at the shoot apex with six distinctly yellow and basifixed stamen, a whorl each of petals and sepals, and a three celled purplish-brown ovary that produces multiple seeds. Like other *Trillium* species, *T. govanianum* is a long-living perennial, with life cycle involving three stages; 1- and 3-leaf vegetative, and 3-leaf reproductive (Fig. 1; Ohara 1989; Chauhan et al.

Fig. 1 Life stages of *Trillium govanianum* in natural habitat

2018, 2019). The plant remains with single leaf stage for several years and continue to increase the biomass of rhizome. When the threshold of the biomass is accumulated in the rhizome; the cycle of several years with non-flowering proceed to flowering stages. At each new season, the plant may revert to the previous stage, presumably if the rhizome's resources have fallen below a threshold (Chauhan et al. 2019). *T. govanianum* appears each year in April after snowmelt, and flowering occurs in May–June. Berry maturity/leaf senescence occurs in July/August at lower, and September/October at higher altitudes, after which the plant became dormant.

2.3 Reproduction

Trillium spp. can reproduce both vegetatively and sexually. Asexual reproduction is less common and is almost absent in some species (Ohara and Kawano 1986; Kubota et al. 2008), while in others it varies across populations and habitat types (Serota and Smith 1967; Gonzales et al. 2008). On the basis of modes of reproduction, Ohara (1989) classified *Trillium* species into three major groups (which were divided into five subgroups—Table 1) including Group 1: This group includes species which exclusively reproduce by sexual reproduction via seeds; Group 2: Species of this group mainly reproduce by sexual reproduction by seeds but vegetative offshoots are occasionally formed in large flowering individuals. Thus, irrespective of the potential of vegetative reproduction, they depend mostly on the seeds for their offspring recruitments; and Group 3: Species of this group reproduce to a large extent by vegetative reproduction, although sexual reproduction plays a role in offspring recruitment. It is also reported that 3-leaf sterile individual rarely produces vegetative offshoots before the sexual reproductive stage. These species occur in ecologically unstable floodplains habitats of the coastal plains.

While considering the *T. govanianum,* detailed reports on reproductive biology and ex situ conservation are not available. However, it is known that the plant reproduces sexually by forming numerous seeds and asexual reproduction occurs rarely in older plants having large rhizomes (Chauhan et al. 2018). The pressing need is to systematically investigate the species for understanding reproductive biology and development of ex situ conservation mechanism.

3 Uses and Active Constituents

Trillium has a long history for its uses in traditional medicines. American species, *T. erectum* is commonly known as 'beth root' and is used by several native North American tribes to treat childbirth pain (Chevallier 1996; Hayes et al. 2009). The Chinese species, *T. tschonoskii* is used to remove carbuncles and ameliorate pain and in the treatment of hypertension, neurasthenia, giddiness, headache, cancer, hemorrhage, hemostasis, antihypertensive, analgesia, detumescence and rheumatism (Wang et al.

Table 1 Reproductive characteristics of some *Trillium* species (Ohara 1989)

Species	Ploidy level	*N*	Biomass (g)	No. of ovules/flower	No. of seeds/plant	Estimated seed setting rate	Reproductive allocation	Single seed weight (mg)
Vegetative reproduction absent								
T. tschonoskii	4X	101	4.2 ± 1.3	153.8 ± 31.1	79.8 ± 33.0	51.8	8.3 ± 2.0	3.4 ± 0.3
T. camschatcense	2X	50	4.3 ± 1.6	225.1 ± 39.8	136.8 ± 32.7	60.7	8.4 ± 2.0	2.9 ± 0.3
T. apetalon	4X	22	4.6 ± 1.4	156.0 ± 27.9	139.4 ± 49.6	89.3	4.9 ± 1.8	3.4 ± 0.8
T. smallii	6X	49	8.1 ± 1.9	216.1 ± 42.1	113.0 ± 30.9	52.2	8.4 ± 2.4	4.4 ± 0.5
Vegetative reproduction rare								
T. grandiflorum	2X	29	4.4 ± 2.1	38.4 ± 11.1	26.0 ± 17.9	67.7	6.0 ± 2.2	6.4 ± 0.8
T. erectum	2X	25	6.9 ± 4.0	105.1 ± 29.2	80.3 ± 78.8	76.4	8.4 ± 2.3	5.0 ± 0.6
T. undulatum	2X	26	3.4 ± 2.3	34.2 ± 3.2	29.2 ± 22.9	85.3	4.7 ± 1.6	4.1 ± 0.3
T. nivale	2X	8	0.5 ± 0.1	27.3 ± 8.9	14.3 ± 5.2	64.1	9.6 ± 1.8	2.7 ± 0.6
T. catesbaei	2X	22	2.6 ± 1.7	53.2 ± 11.2	16.1 ± 8.8	30.2	4.8 ± 1.2	3.1 ± 0.5
T. vaseyi	2X	19	9.5 ± 3.8	41.2 ± 5.0	18.5 ± 15.9	44.9	2.0 ± 0.6	3.0 ± 0.4
T. flexipes	2X	22	6.7 ± 3.3	128.7 ± 43.0	43.9 ± 22.5	34.1	6.3 ± 2.3	4.2 ± 0.7
T. sessile	2X	36	2.6 ± 1.0	124.9 ± 7.9	33.1 ± 16.2	26.5	11.2 ± 4.1	7.8 ± 1.3
T. cuneatum	2X	29	6.8 ± 2.4	160.3 ± 56.8	47.7 ± 20.5	29.7	3.7 ± 1.3	4.0 ± 0.4
T. discolor	2X	22	2.9 ± 0.8	44.0 ± 8.4	21.0 ± 9.0	47.7	4.1 ± 1.4	3.6 ± 0.3
Vegetative reproduction occasional								
T. luteum	2X	28	5.7 ± 1.8	47.3 ± 6.4	32.2 ± 11.8	68.0	3.1 ± 1.0	3.5 ± 0.6
T. viridescens	2X	28	3.0 ± 1.2	111.1 ± 27.9	26.0 ± 13.3	23.4	9.0 ± 4.0	6.8 ± 0.8
T. viride	2X	21	3.2 ± 0.9	67.6 ± 15.1	18.5 ± 11.8	27.3	6.6 ± 3.0	5.7 ± 0.8
T. underwoodii	2X	3	2.4 ± 0.4	75.8 ± 15.7	20.7 ± 13.6	27.3	12.0 ± 5.0	10.2 ± 1.5

(continued)

Table 1 (continued)

Species	Ploidy level	*N*	Biomass (g)	No. of ovules/flower	No. of seeds/plant	Estimated seed setting rate	Reproductive allocation	Single seed weight (mg)
Vegetative reproduction frequent								
T. maculatum	2X	22	3.1 ± 1.6	155.00 ± 6.9	24.2 ± 15.0	15.6	10.1 ± 4.2	8.1 ± 1.4
T. foetidissimum	2X	19	1.8 ± 0.6	57.00 ± 29.8	21.0 ± 12.6	36.8	16.0 ± 6.2	10.9 ± 1.0
Vegetative reproduction abundant								
T. stamineum	2X	10	2.3 ± 0.8	48.7 ± 4.2	14.3 ± 12.6	29.3	6.9 ± 3.2	7.4 ± 1.7
T. ludovicianum	2X	25	4.0 ± 1.5	57.3 ± 18.9	25.30 ± 9.8	44.1	11.17 ± 3.8	10.7 ± 1.0
T. lancifolium	2X	10	1.5 ± 0.6	32.6 ± 4.2	9.70 ± 6.4	29.7	5.96 ± 1.4	4.8 ± 0.5
T. recurvatum	2X	17	2.6 ± 0.8	100.4 ± 20.3	7.80 ± 6.4	7.7	3.55 ± 1.2	4.7 ± 0.8

1978; Fu and Chin 1992; Yu and Zou 2008; Zhan 1994). In the Himalayas, *T. govanianum* is used traditionally for treating cancer, dysentery, open wounds, skin infections, inflammation, sepsis, menstrual and sexual disorder, and for improving general health (Khan et al. 2013; Shah 2006; Pant and Samant 2010; Rani et al. 2013).

T. govanianum has been recently explored for containing active constituents having multiple pharmacological uses. As such, six steroidal compounds (Govanoside A, Borassoside E, Pennogenin, Diosgenin, 20-hydroxyecdysone, 5,20-dihydroxyecdysone) and govanic acid have been isolated from the rhizomes of *T. govanianum* (Rahman et al. 2017a). The most promising explored use of the species is in cancer treatment; rhizome/methanol/butanol extract have shown activity against several cancer cell lines viz. HepG2 cell line (liver), A549 cell line (Lungs), MCF7 cell line (Breast), EJ138 cell line (Urinary bladder) (Khan et al. 2016), HeLa (Cervix) and PC-3 (Prostrate) (Rahman et al. 2015a). The species also exhibits antifungal activity against *Aspergillus niger* ATCC 16888, *Aspergillus flavus* ATCC 9643, *Candida albicans* ATCC 18804, *Candida glabrata* ATCC 90030 (Rahman et al. 2015b) and *Trichophyton rubrum* (Rahman et al. 2017b). Crude extract using methanol and other solvent showed anti-oxidant, anti-inflammatory and analgesic activities (Rahman et al. 2015a, 2016). The methanol extract of the species showed toxicity profile against brine shrimps and leishmanial (Khan et al. 2017).

4 Threats

Trillium species have shown vulnerability to over-exploitation, trade, habitat disturbances, predation and climate change (Chauhan et al. 2019). However, in the case of *T. govanianum* over-exploitation appears most important factor which needs immediate attention for the conservation of the species.

4.1 Over-Exploitation for Trade

Commercial collection of the species was traced from 2010 onwards in Indian Himalayas (Chauhan et al. 2018). Unsustainable gathering for trade is one of the major threats to the species (Chauhan et al. 2019). The populations of the species are declining due to the destructive gathering (Vidyarthi et al. 2013) that supply a traditional medicinal market, where prices have reached USD 50–315/kg (Singh et al. 2017; Chauhan et al. 2018). A survey from some representative villages of Kullu district in Himachal Pradesh reported 637 tons of trade (Vidyarthi et al. 2013). In a recent estimate 200–500 tons of species rhizomes are traded in 2014–2015 (Goraya et al. 2017). The actual amount of trade may be more since trade of the species is illegal and most of the trade is undocumented.

4.2 Habitat

Trillium species prefer cold, shaded and moist climate (Case and Case 1997; Ohara et al. 2006). Most of these species grow as understory in the temperate deciduous forest (Samejima and Samejima 1987; Kawano 1994; Case and Case 1997). However, *T. undulatum* and *T. govanianum*, are reported in the transition zones between hardwood forests and boreal or subalpine coniferous forests (Osaloo et al. 1999). In Indian Himalayas, *T. govanianum* is reported under the canopies of mix temperate (*Quercus* spp., *Abies pindrow*, *Juglans regia*, *Cedrus deodara*, *Picea smithiana*, *Betula utilis*, *Rhododendron* spp., *Juniperus indica*, *Salix* spp.) and sub-alpine forests (*Rhododendron* spp.) with thick humus and slowly decomposing litter. Due to the specific habitat requirement the species has patchy distribution and limited to specific pockets in the Himalayas.

4.3 Herbivory

Chauhan et al. (2018) documented herbivory as a threat to the populations of *T. govanianum*. Herbivory of *T. govanianum* by domesticated animals and wild deer is reported. Grazing has been documented to reduce the performance of other *Trillium* species (Thompson and Sharpe).

4.4 Reproductive Constraints

Trillium are generally self-compatible and has varying levels of inbreeding depressions that results in highly reduced seed set or fruit production (Sage et al. 2001). The seed production in *Trillium* species can also be limited by insufficient pollination (Jules and Rathcke 1999). Vegetative propagation is limited or may be completely missing in some species. The commercial propagation methods for the species are lacking (Nivot et al. 2008) that makes the *Trillium* species more vulnerable. Attempts for mass propagation of *T. govanianum* are in progress, however, preliminary studies do not show encouraging results.

4.5 Climate Change

Climate change is impacting the survival of several high altitude species (Ordonez et al. 2016). Although the effect of climate change on the *T. govanianum* is not studied, however, the studies on other *Trillium* species confirms that climate change may limit these populations to recover from stress (Ream 2011). The emergence of

Trillium in spring was found closely linked to the temperature and change could alter phenological events (Routhier and Lapointe 2002).

5 Conservation

The wild collection to meet the high demand of *T. govanianum* is rampant in the Indian Himalayan Region. A detailed method/approach for conservation is provided, which is based on protection, restoration and sustainable utilization of the species for various purposes (Fig. 2).

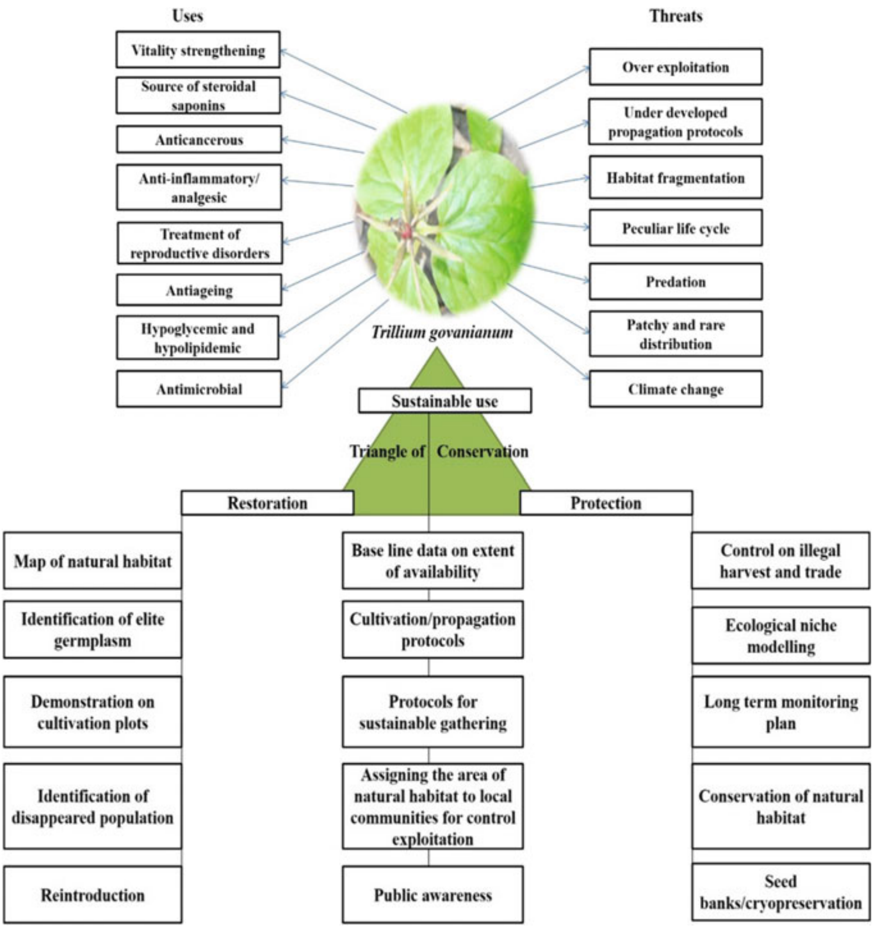

Fig. 2 Schematic diagram showing uses, threats and the proposed methods for conservation and sustainable utilization of *Trillium govanianum*

6 Discussion

Conservation of medicinal plants has been recognized priority agenda at different national and international forum considering their cultural, livelihood and economic significance. The Himalayas are considered as the treasure of medicinal plants diversity harbouring many life-saving medicines. However, overexploitation, habitat loss, parochialism, climate change, and other anthropogenic pressures are posing threats to their survival. Conservation approaches are essentially required for maintaining their gene pool in nature. As per WHO the demand of medicinal plant-based raw drugs is increasing at the rate of 15–25% annually and is expected to reach more than US$ 5 trillion in 2050 (Kala et al. 2006; Booker et al. 2012).

The extinction trends of a particular species are mainly driven by the combination of overexploitation and climate change. The species has a narrow geographic distribution and a highly specific habitat requirement. It is subjected to the unregulated gathering that appears to be reducing its geographic distribution. The narrow distribution range and specific habitat requirements for growth of the species is similar to some Indian Himalayan medicinal plants which are collected for commercial uses (Kala 2005). Grazing by livestock in Indian Himalayas has been regarded as the one of the reasons for declining populations of medicinal plants (Kala 2000; Bhatt et al. 2005), the same may be true for *T. govanianum*. The life cycle of *T. govanianum* is long and is quite similar to other *Trillium* species (Hanzawa and Kalisz 1993; Ohara and Kawano 2005). Chauhan et al. (2018) reported that the oldest rhizome of the species was approximately 30+ years old, likewise 72 years of age was estimated for *T. ovatum* (Jules 1997). The peculiar life cycle and restricted habitat make the species more vulnerable. For other *Trillium* species (*T. ovatum*), it was reported that recovery following stand replacement disturbances was slow (Kahmen and Jules 2005).

The target species, *T. govanianum,* endemic to the Himalayas, is well known for treating several diseases. Pharmacological potential of the species has shown its medical application in a large number of life-threatening diseases including cancer (Khan et al. 2016). Ex situ propagation methods offer mass propagation of elite germplasm that could be used as the substitute for the wild collection and may help in the conservation of the species. However, commercial successful propagation protocols are not available for the species yet.

7 Conclusion

The medicinal value and active constituents of *T. govanianum* have a significant prospect in treating several life-threatening diseases. However, the species is at the risk of local extinction from the Indian Himalayas. The peculiar life cycle, restricted habitat, narrow distribution range, over-exploitation, and increased market value are the major threats to the survival of the species. Limited research has been carried on the ex situ propagation of the species. Public awareness and their inclusion into the policy, habitat restoration, and long term monitoring programmes should be among the top conservation priorities for this species. The proper baseline data on resource availability and environmental requirements for the species is needed for the conservation. There is an urgent need of actions for developing in situ and ex situ propagation protocols, and monitoring of trade and harvesting practices for ensuring the sustainable utilization of the species.

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Assessment of Different Aspects of Elephant Depredation at a Rural Society-Protected Area Interface in Northeast India Based on Public Estimation

Himangshu Dutta and Animekh Hazarika

Abstract Asiatic elephants have been involved in severe conflicts with the people residing in the fringes of Abhaypur Reserve Forest, Northeast India. An attempt was made for the first time ever to assess this problem in these areas. During this study, a closed-ended questionnaire survey was conducted in selected fringe villages of the protected area. The aim was to evaluate the issue from the socioeconomic point of view and also develop a general understanding about the conflict elephants as well as control measures applied. It was revealed that the elephants were responsible for widespread agricultural loss, property damage and human attacks. This resulted in severe consequences upon the financially weak rural population. Due to rampant crop raid, people were also bound to abandon agricultural land and convert paddy fields into tea gardens. The chief control measures applied included crackers, fire and noise, which were not fully effective. The issue has magnified itself into a formidable conservation challenge in the area and needs to be addressed immediately. This would enable humans and elephants to co-exist peacefully around the forest. Human–elephant conflicts around Abhaypur highlight the fact that wildlife can exert widespread impacts upon the human society.

Keywords Depredation · Fringe village · Pachyderm · Reserve forest

1 Introduction

Human–wildlife conflict is the interaction between wildlife and people, which results in a negative impact on people or their resources, or wildlife or their habitat (Steen

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2014). This negative interaction is the most formidable challenge to wildlife conservation worldwide (Fenta 2014). The Ministry of Environment and Forests, Government of India (2011) has recognized it as a serious problem, which needs to be addressed with utmost priority.

In this context, elephants instigate much fear in rural communities because they have the capacity to damage large areas of crops and property, as well as cause human injury and death (Parker et al. 2007). For the survival of elephants in Asia, it is necessary to properly investigate human–elephant conflict so that appropriate mitigation strategies could be implemented (Webber et al. 2011). In India, human conflicts with Asiatic elephants have been extensively studied from the fringes of several protected areas; examples include Nagarahole National Park (Gubbi 2012), Bandipur National Park (Lingaraju and Venkataramana 2014) and so on.

Asiatic elephants have also been causing severe depredations for several decades in the fringe areas of Abhaypur Reserve Forest in Northeast India (Hazarika and Dutta 2018). But no scientific research has been undertaken around this protected area to assess the issue. Quantitative surveys are particularly useful to identify the extent and magnitude of human–wildlife conflicts (Kansky and Knight 2014). Therefore, an attempt was made to assess of the problem in selected severely affected villages located in the fringes of Abhaypur based on the public estimation of losses, and then discuss the losses in the context of socio economic conditions. The aim was to understand the extent of the issue by directly working with the affected people and providing them an opportunity to mention the magnitude of human–elephant conflict as observed by them. In addition, the study also took into account their observations on conflict elephants and control measures applied. For this purpose, a closed–ended questionnaire survey was undertaken in the villages that addressed all these aspects. It was expected that the outcome would help to understand the magnitude of the problem in the area and provide valuable inputs for the management of Asiatic elephants and mitigation of human-elephant conflicts around Abhaypur.

2 Materials and Methods

2.1 Study Area

The Abhaypur Reserve Forest has an area of 6737.85 ha and is situated in the Charaideo District in the state of Assam, Northeast India (Fig. 1). The Abhaypur Range under Charaideo Forest Division is responsible for its jurisdiction. The Forest extends up to the inter-state border between Assam and Nagaland, another Indian state.

The study was conducted from June 2017 to January 2018 in three villages located in the fringe areas of Abhaypur. The studied villages; viz: Gutighat (27° 0′ 28″ N

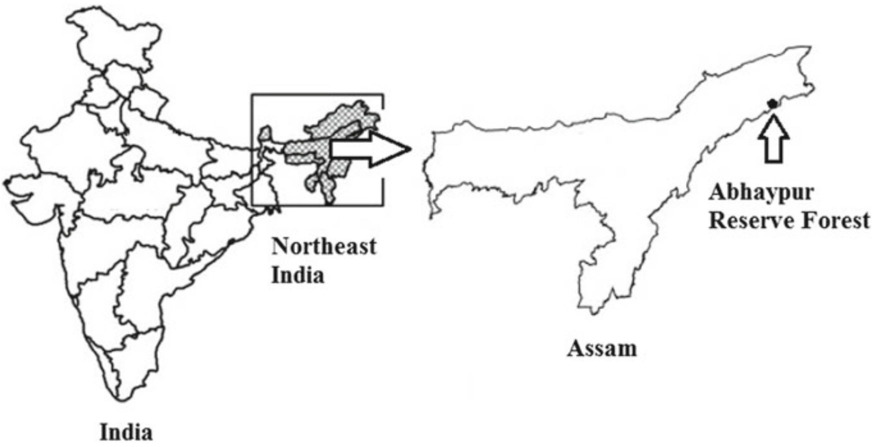

Fig. 1 Location of Abhaypur Reserve Forest in the map of India

and 95° 2′ 7″ E), Guwalapather (26° 59′ 49″ N and 95° 1′ 0″ E) and Hunalipam (27° 0′ 24″ N and 95° 1′ 30″ E) were located adjacent to one-another and were inhabited by Assamese and Tea Garden communities.

2.2 Data Collection and Analyses

At first, pilot visits were made to the study sites. The preliminary information thus obtained was used to prepare a closed–ended questionnaire, which was pre-tested. A final questionnaire for data collection was prepared after incorporating necessary modifications (Fanning 2005; Mathers et al. 2009). Questions were related to socio-economic conditions (type of house, home-garden area, details of family structure, education level, cultivated area, occupation and monthly income), elephant depredation (herd size of conflict elephants, sighting locations, seasons of depredation, reasons due to which elephants come out of forest, type and extent of losses incurred due to elephants and trend of conflicts in the last ten years) and control measures (type of measure applied and effort, effectiveness and suggestions); please refer to Table 1.

The questionnaire was used to survey 25 households from each of the three villages. The total number of households of a particular village (obtained from its headman) was placed as the upper limit in a scientific calculator and 25 random numbers were generated. The households corresponding to the random numbers in that particular village were surveyed. Thus, 75 households were surveyed from the three villages. The heads of the respective households were interviewed but in their absence, the next adult family member was questioned. For this study, the total number of households in the three villages was considered as the unknown population,

Table 1 Questionnaire for human–elephant conflict survey in the Fringes of Abhaypur

Aspect	Question	Options provided (if any)
Household details	House type	Mud/Concrete
	Electrification	Yes/No
	Home garden area	
	Family type	Joint/Nuclear
Family structure (No. of people in a particular household)	Adult males (>18 years)	
	Adult females (>18 years)	
	Minor males (<18 years)	
	Minor females (<18 years)	
	Infants (<05 years)	
Details of education (No. of people in a particular household)	Illiterates	
	Under matriculates	
	Matriculates (10th pass)	
	Higher Secondary pass (12th pass)	
	Others	
Occupation (No. of people in a particular household and monthly income)	Business	
	Stone quarry	
	Private sector	
	Wages	
Cultivated land (area, production and amount of production sold)	Paddy fields	
	Betel nut garden	
	Tea garden	
Livestock reared in numbers	Cow	
	Goat	
	Hen	
	Duck	
	Pig	
	Buffalo	
	Pigeon	
Preparation of local wine		*Prepared/Not prepared*
Information on conflict elephants	Estimated elephant population	
	Maximum observed herd size	
	Minimum observed herd size	
	Most frequently observed herd size	

(continued)

Table 1 (continued)

Aspect	Question	Options provided (if any)
	Ranking four sites (Agricultural field, Human settlement, Road side, River bank) according to the frequency of elephant sighting	Rank 1: Rank 2: Rank 3: Rank 4:
Elephant depredation	Assigning scores to the intensity of conflicts for three distinct seasons in a year on a scale of 0–5	Summer: Winter: Rainy:
	Causes of conflicts	Habitat loss/changes in elephant behaviour/increase in elephant population/Others
Estimation of losses suffered in the last five years	Agricultural loss (area and approximate production)	
	Property loss (cost of property damaged)	
	Human injury (amount spent in treatment) and death	
Historical events of conflict (five to ten years earlier to the present study)	Type of losses suffered	Agricultural loss/Property damage/Human injury/Human death
Abandonment of paddy cultivation and conversion to tea gardens	Area of paddy fields converted to tea gardens and estimated economic profit/loss in last five years	
	Area under paddy cultivation abandoned in last five years	
Control measures	Assigning scores to the efficiency of three mostly used control measures on a scale of 1–5	Crackers: Noise: Fire:
	Money spent to control elephant depredation annually (INR)	
	Time spent in guarding paddy fields (Days in a week, hours per day)	
	Suggested control measures	Relocation of people, elephant translocation,afforestation, electric fencing, elephant squad, trench, others (if any)
Trend in the occurrence of the three aspects of conflicts in the last ten years	Agricultural loss	Increasing/Decreasing/Same
	Property damage	Increasing/Decreasing/Same
	Human attacks	Increasing/Decreasing/Same

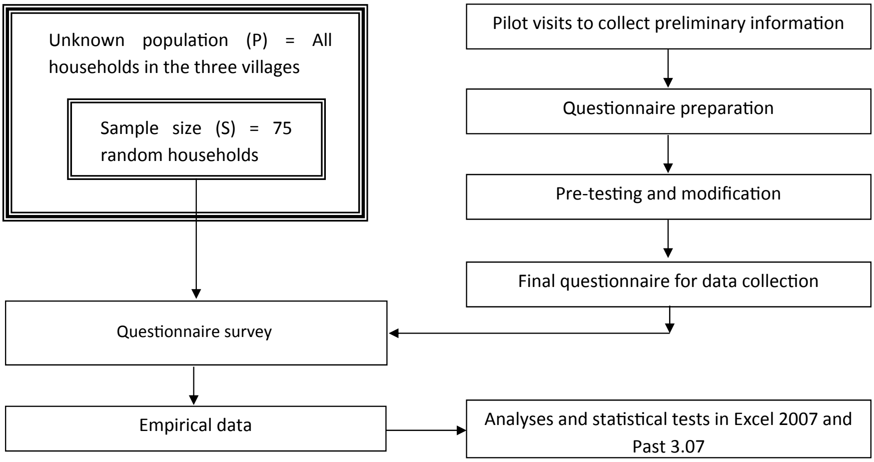

Fig. 2 Study design for questionnaire survey on human–elephant conflict in the three fringe villages of Abhaypur reserve forest, India conducted during June 2017 and January 2018 (Sampling unit = household)

from which a random sample of 75 was drawn. Every household was a sampling unit. The same principle was also applied by Dutta (2017), while conducting questionnaire surveys on wildlife depredation in the fringes of the protected areas in Barak Valley, Assam.

The responses were entered in Microsoft Excel 2007 using binary numbers (0 and 1), whereas numerical values were entered directly. Economic evaluation was done in terms of 'India National Rupee' (INR; 1 INR = 0.015 US Dollars as on 03/04/2018). The data was tested for normality and appropriate statistical tests (Cohen and Holliday 1982) were done in Microsoft Excel 2007 and Past 3.07. The overall study design is shown in Fig. 2.

3 Results

3.1 Socio-economic Condition

Most (70.67%) of the houses were significantly made of mud ($\chi^2 = 12.83$, df = 1, $p < 0.01$) and a significant majority (89.33%) were electrified ($\chi^2 = 46.43$, df = 1, $p < 0.01$). Home garden area ranged from 0.33 to 1.98 acres (Average: 0.51 ± 0.43 acres). A significant majority (74.67%) of the families were nuclear ($\chi^2 = 18.27$, df = 1, $p < 0.01$). Adult males (34.04%) and adult females (33.10%) significantly dominated the village population (F = 58.27, df = 4, 370, $p < 0.01$); sex ratio: 972 adult females against 1000 adult males. There were 1.92 ± 0.94 adult males and 1.87 ± 0.91 adult females per household and the average family size was 7.49 ± 3.6.

People who were unable to complete school education (illiterates and drop-outs) constituted 79.60% of the village population.

In the surveyed villages, 55.63% of the adult population was employed. A significant majority (75.15%) of the earners depended upon daily wages, while the rest were small scale businessmen (13.29%), lower level employees in the private sector (8.23%), stone quarry workers (1.27%) and government servants (5.06%) ($F = 50.06$, df = 4, 370, $p < 0.01$). There were 2.73 dependants against every earner and there was a significant difference between the number of earners and dependants ($z = 5.31$, $n_1 = 75$, $n_2 = 75$, $p < 0.05$). Government service, private sector, business, wages and stone quarry yielded average monthly incomes of 14,875 INR, 7730.77 INR, 7523.81 INR and 4944.74 INR, 3000 INR per earner respectively. Out of the earners 23.42% engaged themselves in additional professions (part-time jobs) to supplement their family income. Wage labour was also the most (48.65%) preferred profession in this regard; other secondary professions included business (32.43%) and private sector (18.92%) ($\chi^2 = 4.98$, df = 2, $p > 0.05$). The monthly family income ranged from 2000 INR to 130,000 INR and the average monthly income per household was 13,043 ± 11,616 INR. There was a significant correlation between the number of earners and the total family income per household ($r = 0.232$, $p < 0.05$).

There was a significant difference ($\chi^2 = 11.23$, df = 1, $p < 0.01$) between number of households which owned agricultural land (30.67%) and the households which did not own agricultural land (69.33%). The average production of paddy was 739.13 ± 458 kg among the households which had the ownership of agricultural land. The average land holding was 1.50 ± 1.00 acres among such households. The production of paddy was significantly correlated with the area of agricultural land ($r = 0.79$, $p < 0.01$). In addition to direct consumption, rice was also used for local beer preparation. In fact, in 36% of the households, rice beer was prepared ($\chi^2 = 5.89$, df = 1, $p < 0.05$). Betel nut gardens were owned by 40% of the surveyed households ($\chi^2 = 3.37$, df = 1, $p > 0.05$); a majority (66.67%) sold the betel nut produced in their gardens. As a whole, a major portion (64.24%) of the betel nut production was sold ($z = 1.04$, $n_1 = 75$, $n_2 = 75$, $p > 0.05$) and the rate of sale varied between 20 and 80 INR per kg. In addition, 41.33% of the households had their own tea gardens ($\chi^2 = 2.27$, df = 1, $p > 0.05$). The average monthly production and income from the tea gardens were 519.03 ± 467.72 kg and 7467.74 ± 4752.07 INR among such households respectively. Tea production was significantly correlated with the area of the tea garden ($r = 0.74$, $p < 0.01$).

Most of the households significantly reared hens (40.5%), followed by cows (39.75%), ducks (17.25%), pigs (25.5%), goats (23.25%), pigeons (3%) and Buffalo (1.5%) ($\chi^2 = 68.50$, df = 5, $p < 0.01$). Hens (51.91%) significantly dominated the livestock population: while cows, ducks, goats, pigs, pigeons and buffaloes contributed 16.55%, 10.81%, 9.57%, 9.35%, 1.46% and 0.34% respectively ($F = 41.33$, df = 5, 518, $p < 0.01$).

3.2 Elephants of the Area in General

Perceived population size of elephants in Abhaypur Reserve Forest varied from 21 to 160. A significant majority (61.33%) stated that the total number of elephants in the area ranged from 41 to 100, while according to some (25.33%) the elephant population was below this range and others (13.33%) stated that the same was above this range ($\chi^2 = 28.11$, df = 2, $p < 0.01$). According to most of the respondents (85%), the minimum herd size of conflict elephants was below ten; among these 26.56% and 17.19% stated that the smallest herd size was three and five respectively. A majority (76%) opined that the maximum herd size ranged from 20 to 60; 21.05%, 17.54% and 15.79% of such people mentioned that the largest herd size of conflict elephants was 25, 35 and 30 respectively. The most frequently observed conflict elephant herd was two (30.67%) and three (25.33%).

Elephants were sighted in four sites; namely agricultural fields, human settlements, road sides and river bank. According to most (93.33%) of the respondents, elephants were most frequently sighted in agricultural fields and all the respondents unanimously stated that elephants were least observed in the river bank.

3.3 Depredation

All households (except one) had historical records (incidents that took place five to ten years prior to the present study) of losses due to elephant depredation. In a significant majority (49.33%), events of agricultural loss ($\chi^2 = 10.92$, df = 2, $p < 0.01$) had occurred in the past, whereas property loss and human injury had taken place in 30.67% and 18.67% respectively.

Human deaths and injuries had taken place in 6.67% and 13.33% of the surveyed households respectively up to five years prior to the present study. The money spent for the treatment of the injured varied between 500 and 8000 INR. Events of property damage had occurred in 30.67% of the households during the same period. The frequency of such incidents ranged from one to five per household. In a majority (47.82%), a single event of property damage had taken place. The estimated economic value of property loss ranged from 500 INR to 30,000 INR within this period. A significant majority (78.26%) of the households suffered from losses between 2000 to 8000 INR ($\chi^2 = 21.48$, df = 2, $p < 0.01$), whereas 17.39% and 4.35% suffered from economic losses above and below this range respectively.

Throughout the same length of time, elephants raided agricultural fields in 45.33% of the households, a majority (58.82%) of which lost between 0.26 to 0.99 acres of cultivated area (area raided varied between 0.07 to 1.65 acres per household). Within the duration of five years, a total area of 1.92 acres under paddy cultivation was raided, which resulted in an overall production loss of 11,020 kg. This amounted to an average loss of 324.12 ± 298.70 kg of paddy among the affected households. Production loss was significantly correlated to the extent of area raided ($r = 0.80$, $p < 0.05$).

Due to severe crop raid by elephants, 40% of the owners abandoned a total of 56.69 acres of agricultural land (including partial and complete abandonment) during the same period. The area of land in which paddy cultivation was quit ranged from 0.50 to 7.9 acres per household. This amounted to an average loss of 1.89 ± 1.68 acres of agricultural land among such households and resulted in an average annual economic loss of 41,833.33 ± 24,826.41 INR. In addition, some owners (16%) converted their agricultural lands into tea gardens in course of five years (a total of 11.73 acres of paddy fields were converted). The average area converted to tea gardens was 0.98 ± 0.48 acres per household.

The villagers were asked to rank the overall intensity of human–elephant conflicts on a scale of one to five across three seasons (summer, rainy season and winter). In this regard, there was as significant difference in the number of people who assigned various ranks to the seasons (H = 10.35, $p < 0.05$). Nobody awarded one to the level of elephant depredation in summer, whereas nobody awarded five to the level of elephant depredation in rainy and winter seasons. A significant majority awarded two (52%), three (38.67%) and four (65.33%) to the intensity of elephant depredation during the rainy season ($\chi^2 = 37.27$, df = 4, $p < 0.01$), summer ($\chi^2 = 70.87$, df = 4, $p < 0.01$) and winter ($\chi^2 = 16.25$, df = 4, $p < 0.01$) respectively.

A majority opined that the overall agricultural loss (89.33%) had been increasing, while human attacks (66.67%) and property damage (45%) had been decreasing in the course of ten years. The significant majority (85.33%) of the villagers identified forest loss as the sole cause of man–elephant conflict in the area; some (12%) stated that both forest loss and increase of elephant population together were responsible and the remaining (2.67%) mentioned an increase in elephant population as the only reason for the problem ($\chi^2 = 92.27$, df = 2, $p < 0.01$).

3.4 Control Measure

The villagers were asked to rank the level effectiveness of the measures (crackers, fire and noise), applied to control elephant depredation in the village, on a scale of 1–5. There was a significant difference in the number of respondents who assigned various ranks to the three measures in this regard (H = 12.99, $p < 0.05$). A majority assigned 4 (42.67%), 3 (45.33%) and 2 (37.33%) to the level of effectiveness of crackers, fire and noise respectively (Table 2). A few respondents (12%) also guarded their agricultural fields at a weekly frequency of four to seven days (@ two to twelve hours per day) when the paddy ripens. The annual expenditure on control measures per household ranged from 100 to 15,000 INR (3252 ± 2768.81 INR on an average). A major proportion (77%) of the surveyed households spent within the range of 1500–6000 INR per year. Afforestation was identified as the sole effective control measure to mitigate human–elephant conflicts in the area by a significant majority (60%); other suggestions included electric fencing (17%); trench (8%) elephant translocation

Table 2 The level of effectiveness of measures used to control elephant depredation in the three surveyed Fringe villages of Abhaypur reserve forest, India ranked on a scale of 1–5 by different proportions (%) of respondents (n = 75)

Type of measure	Rank					
	Zero	One	Two	Three	Four	Five
Crackers	9.33	0.00	5.33	40.00	42.67	2.67
Fire	1.33	0.00	13.33	45.33	40.00	0.00
Noise	25.33	1.33	37.33	16.00	17.33	2.67

Zero = Ineffective; Five = Highly effective

(6.67%); elephant squad (2.67%); electric fencing and trench (2.67%); afforestation and electric fencing (1.33%); afforestation, electric fencing and trench (1.33%) ($\chi^2 = 166.81$, df = 7, $p < 0.01$).

4 Discussion

The surveyed villages represented a typical rural society of Assam, characterized by mud houses and extensive paddy cultivation. Assam experiences plenty of rainfall and possesses fertile land which is highly suitable for paddy (Islam 2012). Thus, rice (*Oryza sativa*) was the chief agricultural crop around the Forest. Seeds are usually sown in seed beds in the month of May. The emergent shoots are later transplanted to paddy fields and finally the crop is harvested in December. A similar system of paddy cultivation is also practiced in Cambodia (Webber et al. 2011).

Small tea gardens provided a reliable source of income for the villagers and efficiently supplemented local livelihoods. In fact, Assam is well known for producing high quality tea with fine aromatic quality and contributes about a sixth of the tea produced in the world (Arya 2013). Along with tea, betel nut plantations also helped in income generation. Thus, the three plant products (paddy, betel nut and tea) played an important role in village economy. Another important characteristic of the villages was the presence of a large population of livestock. Hens and cows were the most commonly reared livestock. Agriculture and livestock are important sources of livelihoods in forest fringe villages, which in turn depend extensively on the forest for various inputs (Banerjee and Chowdhury 2013).

The huge proportion of under-matriculates (people unable to complete school) indicated the poor level of education in the villages. This was a severe problem because education is also a fundamental factor in achieving food security for rural populations in developing countries (Burchi 2006). Due to the lack of proper education, the villagers mostly depended upon daily wages for their livelihood, instead of engaging themselves in professions that provided better financial security. In addition, large families (average family size was over seven) acted as financial burdens on the household earners. It was evident from the fact that the number of dependants was almost thrice the number of earners.

The fringes of protected areas and landscapes where such human development and wild land are intermingled are most prone to wildlife depredation (Treves 2007). This was very well proved by human–elephants conflict that occurred throughout the year in the fringe areas of Abhaypur. Conflicting situations between humans and elephants have also been documented from the periphery of Patheria Hills Reserve Forest in South Assam and have been found to exert severe impacts (Dutta et al. 2018). The same can be mentioned with respect to elephant depredation in the studied villages. Consequences of human–elephant conflict can be direct or indirect. Direct impacts have effects upon the physical and economic well-being whereas indirect impacts exert social consequences upon people (such as fear, hampering of normal activities, costs etc.) (Parker et al. 2007).

Widespread paddy loss was an important facet of elephant depredation in the villages. This had a severe negative impact upon the socio-economic conditions because agriculture was an important means of livelihood for the villagers. Due to severe elephant raids, villagers decreased paddy cultivation near the reserve and this led to land abandonment. Several residents even completely quit agriculture and instead made wages. This was well understood by the fact that in course of five years, about 45% of the households suffered from severe crop raid and consequently the ownership of agricultural land that was actually cultivated fell down to about 30% (see results). Thus, the elephants moved beyond the fringe areas to additional sites in pursuit of paddy. Greater movement to distant paddy fields through human settlements resulted in a higher intensity of conflicts on the way. Severe paddy depredation by elephants has also been reported form the vicinity of Manas National Park and Biosphere Reserve, Assam (Nath et al. 2009). Besides, in the fringe villages of Abhaypur large home gardens abundant in fruit trees also attract elephants.

The climate of Assam is highly suitable for tea production (Arya 2013) and a common practice in response to paddy depredation was to covert paddy fields into tea plantations. However, this needed initial investment and all villagers were not financially capable of arranging the required capital. Small tea gardens yielded a steady income. Apart from this, many incidents of human attacks (limb, chest and hip injury) and property damage also occurred, which resulted in economic consequences on the economically weak rural population. Even human death, which is the ultimate form of human–wildlife conflict (Gurung et al. 2008), had also taken place. A reason for this could be the local wine production and consumption, the smell of which is often stated by the general public to attract elephants into human settlements and drunken individuals. Thus, as a whole, it can be agreed with Jadhav & Barua (2012), who stated that the wellbeing of marginalized people is severely affected by human–wildlife conflicts. Images 1 and 2 depict the pictures of elephant depredation around Abhaypur.

Residents in the fringe villages had widely different opinions about the size of elephant population inside the Reserve Forest as well as the herd size of conflict elephants. However, a significant majority identified habitat loss as the reason of elephant depredation. Thus, it was precise that the visual perception of the emerging

Image 1 A homegarden destroyed by elephants in the Fringes of Abhaypur reserve forest

Image 2 A house destroyed by elephants in the Fringes of Abhaypur reserve forest

elephants varied, but the level of understanding on the causes of depredation was almost the same. Most of the respondents also opined that the elephants were mostly sighted in agricultural fields and this indicated that paddy cultivation efficiently attracted the elephants.

Human–wildlife conflicts are mostly driven by the availability of resources or the lack of them (Brooks and Maude 2010) and this was evident in the fringe villages. In this case, massive habitat destruction due population growth (especially, due to immigration of flood displaced people from different parts of the state) and human developments were the main causes. Hazarika and Dutta (2018) did a qualitative study in the area found that people have settled in the migratory corridor between Abhaypur and nearby Sola Reserve Forest located at a distance of about 30 km. They also state that when elephants are driven away into the forest by the forest administration of Assam, they moved to Nagaland on the other side. But they are again chased back from Nagaland and hence, the elephants returned. Thus, we state that the resulting hindrance to movement, administrative/management reasons, and shortage of food resources caused the elephants to move out of their habitats into the forest fringes, where ample amount of paddy was available for raiding. Intensified land use results in habitat loss, degradation and fragmentation and this causes elephants to come into greater contact with humans, especially in cultivated areas (Chartier et al. 2011).

Measures applied by forest department and villagers (crackers, fires and noise) were mostly partially effective and in some cases, completely ineffective. The villagers not only lighted fires around paddy fields, but also threw balls of fire to chase away elephants. However, crackers were comparatively more effective than fires and noise (as indicated by the scores provided by the villagers in Table 2). A few also guarded their agricultural fields and some even pelted stones. People also sometimes informed the forest department when elephants were sighted and expected necessary action. Application of control measures required financial inputs and a considerable investment of time (in case of guarding). Thus, the issue needs to be addressed as it can jeopardize wildlife management, as evident in several Bolivian protected areas, where crop depredation by wildlife has threatened management and conservation (Pereza and Pacheco 2006).

Human–wildlife conflicts are sometimes trans-boundary in nature and as a result collaboration between different local jurisdictions and under certain circumstances two or more countries might be required (Nature Conservation Division, Royal Government of Bhutan 2008). Under the studied situation, the issue in Abhaypur required the intervention of the forest administrations of two Indian states. Compensation and insurance schemes can be introduced around Abhaypur. Such schemes have been implemented around protected areas in Namibia, Nepal and Kenya (Bowen-Jones 2012). Compensation of losses arising from human–wildlife conflict increases tolerance level of the community towards wildlife (Ogra and Badola 2008). Cultivation of crops not edible to edible to elephants can also be considered as a mitigation measure, which can even be subsidized for the benefit of the victims. In fact, the cultivation of alternative crops has also been suggested by Neupane et al. (2017) to control human–elephant in southern Nepal. The villagers provided valuable suggestions regarding the control measures that should be applied. Steps should be taken include them by management authorities. Habitat restoration through afforestation holds great promise in this regard (in the light of responses).

From the above, it is understood that the impacts of human–elephant conflicts around Abhaypur Reserve Forest, Assam were more severely felt because of the poor socio-economic conditions. The issue was complex because the involvement of the forest administration of two different states and an endangered species protected under law. Moreover, the problem was also likely to intensify further, with ongoing developmental activities. The solution is to proceed with initiatives that not only conserve the protected area, but also secures rural livelihoods. This is the only way to make human–elephant co-existence a reality in Abhaypur.

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Exploring Synergistic Inter Linkages Among Three Ecological Issues in the Aquatic Environment

Himangshu Dutta

Abstract Eutrophication and species invasion are formidable problems triggered by the effects of anthropogenic activities in the aquatic environment. Several researchers have highlighted the synergistic impact of climate change on specific aspects of the two problems separately. There is a need of scientific literature that depicts all the existing inter linkages simultaneously so that a complete understanding could be developed. This would enable the development of appropriate mitigation measures; especially in the present times when ecosystems are exposed to multiple environmental issues. The present review addresses this lacuna in the aquatic ecosystem and is the first hand approach to simultaneously link climate change with eutrophication and species invasion. Statistical analysis revealed that such linkages play an important role in magnifying the issues and should always be considered while devising mitigation measures. Aquatic ecosystems can then be effectively conserved and protected against the harmful effects of global change.

Keywords Aquatic ecosystem · Climate change · Eutrophication · Species invasion

1 Introduction

Human activities exert a widespread influence on almost every major aquatic ecosystem in the world (Smith 2003). An important human-induced issue of the present times is climate change (Dutta 2017). In the marine ecosystem, climate change exerts profound consequences on individual performance, distribution and abundance. It also affects abiotic variables (e.g. ocean chemistry and circulation) that have a complex interaction with biological processes (Harley et al. 2006). Freshwater species are also highly vulnerable to climate change and have suffered from extinctions and extirpations (Heino et al. 2009).

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In the terrestrial ecosystem climate change has been found to accelerate three other current ecological issues (habitat destruction, fire and alien plant invasion) triggered by anthropogenic activities (Dutta 2018). It is likely that such relationships between climate change and human-induced issues also exist in the aquatic ecosystem(s) which must be understood to devise proper mitigation measures. Therefore, the present review has been attempted to understand the synergistic inter linkage among climate change, and two important problems of the aquatic environment; viz: eutrophication (Anderson et al. 2002) and species invasion (Otero et al. 2013; Xiong et al. 2018) that arise due to the impact of human activities. The aim is to develop an understanding about the role played by climate change in facilitating the two issues. The review does not concentrate upon the direct negative effects of climate change on aquatic biodiversity and presents it as a catalyst. It is the first hand approach to simultaneously inter link climate change with the two issues and has the following three objectives:

a. To understand the causes and negative consequences of eutrophication and species invasion in order to relate them to the effects of climate change.
b. To understand the synergistic relationship of climate change with eutrophication and species invasion as well as the inter linkage between eutrophication and species invasion.
c. To test the statistical significance of the inter linkages.

2 Materials and Methods

The overall review has been conceptualized on the basis of the method used by Dutta (2018) to link climate change with three other ecological issues in the terrestrial ecosystem. Scientific literature related to the impacts and causes of eutrophication and species invasion and their linkage with climate change was downloaded from Google Scholar. Research publications that linked eutrophication and species invasion were also obtained. After this, the literature was converted into empirical data based on six phenomena and six categories of ecosystems formulated on the basis of the gathered information. Chi-square analysis was performed to test the overall significance.

3 Results

3.1 Species Invasion in the Aquatic Environment

3.1.1 Invasion as a Problem

Invasive species are often functionally different from the components of the recipient community and give rise to ecological impacts that propagate through the food web (Gallardo et al. 2016). Aquatic ecosystems are at a great risk to the introductions of such species, which trigger major disruption in their functioning (Anđelković et al. 2016). Aquatic habitats often consist of interconnected waterways in which vectors easily enable artificial transport of species and their propagules. Thus, the characteristics that commonly facilitate biological invasions in terrestrial habitats are not necessary in aquatic environments. Therefore, features that enhance consumption and growth substantially increase the probability of establishing and spreading when a particular species enters a new ecosystem (McKnight et al. 2017).

The negative impacts of invasive species include habitat damage, community change, incidence agricultural and aquaculture pests, loss of biodiversity and genetic pollution/extinction. Such species also threaten marine industries like fishing and tourism as well as human health and marine infrastructure (Bax et al. 2003; Chen et al. 2017). Exotic species not only lead to biodiversity loss by elevating extinction levels, but also by depressing speciation in ecosystems (Stigall 2011).

Economic globalization has accelerated the expansion of exotic species and their impacts of ecosystems have become global issues (Gurevitch and Padilla 2004). Anthropogenic activities such as aquaculture, biocontrol, shipping, stocking, canals and aquarium trade play a crucial role in spreading aquatic invasive species (Molnar et al. 2008; Xiong et al. 2018). Recreational boating is also a major vector that facilitates primary introduction and secondary spread of marine alien species (Murray et al. 2011). The role of human activities in this context is evident from the fact that human vessels, aquaculture, wild fisheries and live food trade serve as important pathways for the introduction of alien species in the Arctic (Chan et al. 2019). Another relevant instance is The Suez Canal, which has played an important role in the introduction of invasive species (e.g. Lessepsian fish species) to the Mediterranean (Otero et al. 2013).

3.1.2 Freshwater Invasion

Alien plant invasion is a formidable threat in this context, but its impacts have been studied less in freshwater ecosystems compared with terrestrial habitats (Stiers et al. 2011). However, freshwater ecosystems are more vulnerable to invasions by alien species than terrestrial ecosystems (Sala et al. 2000; Coetzee et al. 2009). In such ecosystems, invasive plants lead to the losses of species diversity and contribute to water quality deterioration (Wang et al. 2016). In fact, invasive aquatic plants have resulted in high local extinction of endemic species (Ding et al. 1995). For instance, the endemic aquatic plant *Ottelia acuminate* faced local extinction due to alien plant invasion in the plateau lakes of China (Xiang et al. 2013). On the other hand, the expansion of invasive macrophytes has led to the greatest decrease in fish abundance (Gallardo et al. 2016).

An example of an invasive aquatic plant is the Eurasian water milfoil, which can displace and outnumber native aquatic plants as well as reduce their habitat and diversity in lakes (Zhang and Boyle 2010). *Hydrocotyle ranunculoides*, *Ludwigia grandiflora* and *Myriophyllum aquaticum* are important invasive plants of Belgium. Their introductions have led to severe ecological alterations in native vegetation and detritus community in the ponds of Belgium and this has negatively affected invertebrate abundance in affected ponds (Stiers et al. 2011). On the other hand, *Vallisneria spiralis*, *Azolla filiculoides* and *Elodea nuttallii* are the most abundant non natives of Serbia. Most of the aquatic invasive plants of Serbia are native to the Americas. (Anđelković et al. 2016). However, there are 152 invasive aquatic plant species in China and the majority were introduced from South America followed by North America, Asia, Africa, and Oceania (Wang et al. 2016). But there is a lack of adequate information on such plants in both China (Wang et al. 2016) and Serbia (Anđelković et al. 2016). In fact, biological invasions in aquatic ecosystems have also been mostly overlooked in China, even though their negative effects are frequently observed (Chen et al. 2017). This can be exemplified by species such as mosquito fish (*Gambusia affinis*) and water hyacinth, which have caused great ecological and economic problems in the Three Gorges Dam Reservoir in China (Xiong et al. 2018).

Apart from plants, molluscs, fishes and decapods also invade freshwater ecosystems and impose their own respective negative effects depending upon their role and function (Strayer 2010). Nonnative crayfish is another example in this regard. Invasive crayfish affects biodiversity and ecosystem functioning and leads to negative consequences on basal resources, invertebrates, amphibians and fish (Twardochleb et al. 2013). Greater numbers of non-indigenous crayfish of pet trade origin are becoming established particularly in Europe and their negative effects are expected on freshwater ecosystems (Kotovska et al. 2016).

The Common carp *Cyprinus carpio* is a major invasive fish of the freshwater ecosystem (Bajer et al. 2015). The introduction of this species led to severe reduction in plant cover and richness in several Great Plains lakes and Eastern Temperate Forests lakes in North America. It illustrates the consequences of introducing nonnative ecosystem engineers to lakes (Bajer et al. 2016). On the other hand, in England introduced Ruffe (*Gymnocephalus cernuus*) and cyprinid roach (*Rutilus rutilus*) have become invasive. Vice versa, native Coregonid whitefish (*Coregonus lavaretus*) is an example of a fish negatively affected by alien fish species in Loch Lomond in Scotland (Winfield et al. 2011). Several negative associations have been identified between native and introduced nonnative species of trout in Western United States (Dunham et al. 2004). This has also led to indirect effects, as evident from the fact that the reductions in the native cutthroat trout in and around Yellowstone Lake has resulted in changes the distribution, diet, survival and abundance of river otters (Crait et al. 2015). On the other hand, overwintering waterfowl in Lough Neagh, Northern Ireland has been negatively affected due to the introduction the Cyprinid roach (*Rutilus rutilus*) (Winfield et al. 2011).

3.1.3 Marine Invasion

Introduction of alien species is considered as major a threat to marine biodiversity (Bax et al. 2003). In fact, marine invasive species have caused widespread local population extinctions all over the world and have been identified as the second biggest reason of biodiversity loss after habitat destruction (Breithaupt 2003). Zaiko et al. (2007) conducted a comparative vulnerability analysis of 16 selected benthic habitat types in the SE Baltic Sea waters and the Curonian lagoon and found that species richness of alien species was higher in lagoon habitats than the sea. They also found that salinity, depth range and availability of a hard substrate were the most important physical factors that determined the distribution of native and invasive species.

An important example in this context is the Mediterranean, which has suffered severe biodiversity loss due to marine aliens (Galil 2007). The Asian date mussel *Arcuatula* (*Musculista*) *senhousia* is global invader that has affected the estuaries in the Mediterranean (Munari 2008). Another instance is the Caribbean, where invasive Indo-Pacific lionfish has given rise to several negative impacts on the coral reef food-webs (Arias-González et al. 2011). In fact, the exponential population growth of this predatory species in the western Atlantic, Caribbean Sea and Gulf of Mexico has drastically reduced the abundance of small native on some coral reefs (Côté et al. 2013).

Invasive species such as the Comb Jelly *Mnemiopsis leidyi*, Asian clam *Potamocorbula amurensis* and the crab *Carcinus maenas* have resulted in severe losses in fisheries in the Black Sea, San Francisco Bay and North American east coast respectively (Shiganova 1998; Grosholz et al. 2000). In Kas-Kekova Marine Protected Area, Turkey, the grazing pressure by two fish populations (*Siganus luridus* and *S. rivulatus*) from the Red Sea shifted the original habitat to one dominated only by low-lying and turf-forming algae (Sala et al. 2011). Invaders like the American oyster *Crassostrea gigas* and the Japanese carpet shell *Ruditapes philippinarum* invaded lagoon environments such as the Thau lagoon in south-western France and modified the ecosystem up to an extent that these species have become an important part of the biomass and diversity of the lagoon flora and fauna (Boudouresque et al. 2011). On the other hand, invasive crabs (*Carcinus maenas* and *Hemigrapsus sanguineus*) have been reported from the intertidal zones of several coastal states of the US such as New Jersey to Maine (Delaney et al. 2008). Marine invasive species have also been reported from Pearl Harbor in Hawaiian Islands (Coles et al. 1999), Port Phillip Bay (Hewitt et al. 1999), New Zealand (Cranfield et al. 1998), Baltic Sea, Black Sea, Sea of Azov and Caspian Sea (Paavola et al. 2005) and Italian coasts (highest number has been observed in the northern Adriatic Sea) (Occhipinti-Ambrogi et al. 2011).

3.2 Eutrophication

3.2.1 Algal Blooms

Algal blooms are dense aggregations of phytoplankton cells of one or more species and accumulate in water until their growth is checked by resource depletion. Nutrient availability is the primary requirement for their buildup because phytoplanktons grow by taking up dissolved nutrients and incorporating them into biomass (Assmy and Smetacek 2009). When excessive nutrients accumulate in the aquatic ecosystems the phytoplankton community shifts to bloom-forming algae. This persistent condition of surface waters is called eutrophication (Smith 1990; Carpenter 2005). Eutrophication leads to predictable increment of the biomass of algae in both freshwater and marine ecosystems (Smith 2003) and occurs due to nitrogen and phosphorus enrichment (Johnson et al. 2007; Frumina and Gildeeva 2014). Globally, total nitrogen input has been strongly correlated with phytoplankton production in estuarine and marine waters, whereas total phosphorus input has been strongly correlated with phytoplankton production in freshwaters (Anderson et al. 2002). The concentration of nutrients prior to its outbreak determines the magnitude of the bloom peak (Assmy and Smetacek 2009). The potential sources of nutrients that stimulate algal blooms are atmospheric deposition, sewage, groundwater flow, as well as runoff and discharge from agriculture and aquaculture (Anderson et al. 2002). Examples of blooms due to nutrient loading can be cited from U.S. mainland estuaries (Chesapeake Bay and the Albemarle-Pamlico Estuarine System), Inland Sea of Japan, the Black Sea, and Chinese coastal waters (Anderson et al. 2002), coastal waters of Lee County, Florida (Lapointe and Bedford 2007) and Gulf of Mexico (Henrichs et al. 2015).

3.2.2 Cyanobacteria as a Problem

The increment of cyanobacterial dominance in phytoplankton communities worldwide has been linked with eutrophication (Smith 2003). Cyanobacteria are the oldest oxygen evolving organisms of the earth and have played an important role in shaping the present biosphere (Paerl and Paul 2012). They are the most ancient group of phytoplanktons and form harmful algal blooms in freshwater, estuarine, and marine ecosystems (O'Neil et al. 2012). Certain cyanobacterial species form massive surface growths that produce toxins, deplete oxygen and alter food webs. Such bacteria are benefitted by nutrient enrichment (eutrophication), and hydrologic modifications like water withdrawal, reservoir construction (Paerl and Huisman 2009). Examples of cyanobacteria that secrete potent toxins are *Microcystis*, *Anabaena*, and *Nodularia* and blooms of these species can give rise to severe problems (Assmy and Smetacek 2009). The toxic and non-toxic strains of several bloom-forming cyanobacteria occur together and cannot be distinguished visually (Davis et al. 2009).

3.2.3 Impacts of Algal Blooms

Decomposition of algal blooms leads to oxygen depletion and severe negative ecological impacts including the death of fishes (Carpenter et al. 1998; Smith 1998). In fact, as eutrophication increases, piscivorous fish and zooplankton grazers decline, and there is an increase in foraging fish and algae (Moss et al. 2011). In fresh waters, climate change and eutrophication are likely to reduce the diversity of macrophytes, which in turn threatens the faunal diversity of aquatic ecosystems (Chambers et al. 2008). Eutrophication has also been linked with the emergence of wildlife diseases through direct and indirect pathways (Johnson et al. 2007). It makes water unsuitable for fisheries, recreation, industry, and drinking because of increased growth of undesirable algae and aquatic weeds and the oxygen shortages caused by their death and decomposition (Khan 2014). When nutrient enrichment and eutrophication cross a certain threshold even the physiological performance of coral individual and ecosystem functioning of coral reefs are negatively affected (D'Angelo and Wiedenmann 2014). Moreover, extensive blooms of toxic cyanobacteria on the surface of eutrophic lakes cause widespread mortality in fish and birds, and also threaten the health threat of cattle, pets and humans (Jöhnk et al. 2008a). Harmful algal blooms are also formed by some other species such as *Karenia brevis* which have also given rise to problems like death of fish, respiratory irritation in humans and closures of shell fishing (Henrichs et al. 2015).

3.3 Synergistic Inter Linkage of Climate Change with the Two Problems

3.3.1 Climate Change and Aquatic Alien Invasion

Climate change increases the competitive and predatory effects of non native species on native species (Rahel and Olden 2008). It also magnifies the impacts of invasive species already present by enhancing the virulence of diseases, and its direct effects on habitat quality enable invasive species to expand into new areas (Rahel et al. 2008). This occurs because warming exerts stress on the native dwellers and facilitates the arrival of aliens (Harris and Tyrell 2001) because stressed ecosystems are highly vulnerable to invasions (Strayer 2010).

Climate change indirectly affects local communities by increasing the dominance of introduced species (Cascade et al. 2010). This is understood in the context of introduced invertebrates in which the rates of growth and recruitment are accelerated by warming relative to the natives, leading to their greater dominance. It is in fact the main reason due to which the establishment of nonnative ascidians in New England very well concurs with increases in winter water temperatures (Stachowicz et al. 2002). A similar fact can be observed in the marine fouling communities of Bodega Harbor, California, USA. In this case, introduced species have been found to be more tolerant towards higher temperatures than natives. Thus, during ocean warming scenarios, there is increased growth and survival of the early stages of aliens in such communities, compared with the natives. This in turn aids in the subsequent competitive interactions and community development (Cascade et al. 2010). High temperature and carbon dioxide level also accelerate the growth rates of the invasive aquatic dioecious plant hydrilla (*Hydrilla verticillata*) and enables it to spread more rapidly within and outside of its current range (Chen et al. 1994). The populations of another invasive species the common reed, *Phragmites australis* have also been found to increase under elevated ambient air temperatures (Wilcox et al. 2003). The three well known European invasive aquatic plants *Hydrocotyle ranunculoides*, *Ludwigia grandiflora* and *Myriophyllum aquaticum* prefer high light intensity and temperature and are expected propagate well under climate change (Hussner 2009).

Climate change eliminates cold temperature or winter hypoxia that hampers survival. Its effects result in the construction of greater number of reservoirs that serve as hotspots for invasive species. Such consequences increase the possibility of establishment of new species. Another impact of climate change is flood, which helps in the transportation of invasive species to newer sites (Rahel and Olden 2008). This is much relevant with respect to the invasive weed *Mimosa pigra* because its dispersal is mainly affected by flooding and rainfall in Australia (Lonsdale 1993). In fact floods play an important role because the seeds of wetland invasive plant seeds are frequently dispersed by water (Zedler and Kercher 2004). Other effects of global warming such salinity rise and oceanographic forcing also enhance biological invasions (Raitsos et al. 2010). Warming can also increase in the number of sexual versus asexual reproductive periods and thus lead to greater rates of spread of aquatic invasive species (USEPA 2008). In addition, due to warming, the expansion of parapatric species may occur into new habitats, which in turn can have detrimental impacts similar to those of invasive species (Rahel et al. 2008).

As a whole, rising temperatures have modified the available thermal habitat of warm-water species and thus, facilitated their settlement rapidly. The rate of alien species invasion due to global warming has been more than the rate of temperature rise. This has triggered severe threats to Mediterranean Sea biodiversity (Raitsos et al. 2010). Climate change has also been projected to severely intensify species invasion in the Arctic and the Southern Ocean (Cheung et al. 2009). In fact, in the Arctic, climate change and increased anthropogenic activities are likely to accelerate the introduction of alien species (Chan et al. 2019). Thus, under the influence of climate change new prevention and control strategies might be required to control invasive species that at present exert only moderate effects or are limited by unfavorable climatic conditions (Rahel and Olden 2008).

The negative effect of climate change can be understood from the fact that fish communities dominated by cold-water species (physiological optima <20 °C) in temperate regions are at the risk of displacement by non-native cool-water (physiological optima 20–28 °C) and warm-water fishes (physiological optima >28 °C). Warming enables such fishes to invade by decreasing the thermal constraints on the expression of their life history traits (Britton et al. 2010). In the context of fishes, the

Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) is an important example. This freshwater species presently occupies only 42% of its historical range and is severely threatened by species invasion that has resulted in hybridization, predation, disease, and severe inter specific competition (Gresswell 2011). The introduction of lake trout (*Salvelinus namaycush*) to Yellowstone Lake in Yellowstone National Park has triggered this problem (Wengeler et al. 2010). Now, the Yellowstone cutthroat trout is expected to be benefitted by warmer stream temperatures caused by climate change. But the simultaneous positive effects on the growth of the non-native species is likely to offset such benefits through inter specific effects (Al-Chokhachy 2013).

3.3.2 Climate Change and Eutrophication

Climate change is likely to increase harmful cyanobacteria in eutrophic ecosystems (Jöhnk et al. 2008a). This is because climatic change has been predicted to raise temperatures, enhance vertical stratification of aquatic ecosystems, and alter seasonal and annual weather patterns; all such changes promote harmful cyanobacterial blooms in eutrophic waters (Paerl and Huisman 2009). The stability of water column increases under high temperature and consequently vertical turbulent mixing is reduced. This provides competitive benefit to buoyant cyanobacteria. In fact, the direct and indirect impacts of warming, along with reduced wind speed and cloudiness, as well as summer heat waves boost the development of harmful cyanobacterial blooms (Jöhnk et al. 2008a). Warming can also enable productive cyanobacteria to invade greater latitudes (Wiedner et al. 2007). As a whole, the effects of climatic change, especially higher temperatures, greater vertical stratification and salinization, and intensification of storms and droughts modulate the frequency, intensity, geographic distribution and duration of cyanobacterial prevalence (Paerl et al. 2011). The role of warming is in this regard is evident from the fact that blooms of toxic cyanobacteria often occur in eutrophied ecosystems during warm months in temperate latitudes (Davis et al. 2009). Another aspect is the food web because the direct impacts of nutrients interact with the structure of food webs, which in turn are influenced by climate (Moss et al. 2011).

Paerl and Paul (2012) studied the anthropogenic and climatic influence in freshwater and marine environments and found that these factors synergistically promote the dominance and persistence of harmful bloom-forming cyanobacteria. This synergy alters bloom potentials in response to changes in thermal and hydrologic regimes. However, changes in the thermal regime induced by climate, rather than direct effects of temperature positively affects cyanobacterial dominance (Wagner and Adrian 2009). When the aquatic environment becomes warmer the biomass of large *Daphnia* also declines and its ability to control phytoplankton decreases. Consequently, algal crops increase with warming. However, cyanobacteria have high temperature optima for growth and their resistance to grazing by small zooplanktons increases with temperature. Hence, the proportion of this sometimes-toxic group is likely to increase (Jöhnk et al. 2008b; Elliot 2010).

Physiological and physical factors enable cyanobacteria to dominate phytoplankton assemblages under higher temperatures (O'Neil et al. 2012). In fact, physiological traits specific to cyanobacteria provide them much advantage compared with other taxa under such conditions. Hence, the effects of climate change have been predicted to exert substantial effects on phytoplankton species composition and biomass in freshwaters and potentially favour cyanobacteria over other phytoplanktons. As a whole, cyanobacteria as a group are likely to increase in most regions in the future (Carey et al. 2012). In this context, Kosten et al. (2012) state that warmer climates do not increase the overall phytoplankton biomass but the percentage of the total phytoplankton biovolume attributable to cyanobacteria increases steeply with temperature. Their results indicated a synergy between nutrients and climate. The genus *Microcystis* is an important example in this context. Experimental results indicate that higher temperature and phosphorous levels would yield higher growth rates in the toxic strain of this cyanobacteria, compared with its non-toxic strain. So, future eutrophication and climatic warming are predicted to promote the growth of toxic, rather than non-toxic populations of *Microcystis* (Davis et al. 2009).

Greater input of nutrients and rising temperatures synergistically intensify the symptoms of eutrophication (Moss et al. 2011). Climate change leads to intense storms that increase soil erosion and thus nutrient delivery is increased. At times, it decreases rainfall in summers or gives rise to dry seasons and consequently, the water levels diminish in lakes. As a result, nutrients that are already present become concentrated and the marginal sediment is exposed to mineralization and nutrient release. Residence times are also increased. This favours the propagation of persistent phytoplankters such as cyanobacteria (Moss et al. 2011). Apart from these, warming soils, and melting glaciers (Jeppesen et al. 2011) and higher rates of mineralization in catchment soils (Rustad et al. 2001; Brookshire et al. 2011) due to climate change also contribute to nutrient loading. Moreover, warming causes greater deoxygenation at the surfaces of lake sediments and so more nutrients are released in summer (Jensen and Andersen 1995). Nutrients are also likely to increase in the marine environment. This is understood from the fact that climate change is likely to trigger temperature fluctuations that could affect the oceanographic features in the Mediterranean. Consequently, nutrient enrichment and plankton blooms are expected to occur (CIESM 2008).

3.4 Assessment of Synergistic Effect of Climate Change on Eutrophication and Species Invasion

3.4.1 Criteria for Assessment

Assessment has been done based on the following six phenomena (A-F). These specific phenomena have been identified as the criteria for assessment because they comprehensively summarize the synergistic effect of climate change on eutrophication and species invasion understood the current literature survey. The phenomena are valid only for aquatic ecosystems affected by eutrophication or species invasion or both the issues. One or more of the phenomena can occur in a particular ecosystem, depending upon its ecological condition.

A. Climate change facilitates eutrophication by increasing nutrient input.
B. Climate change accelerates the symptoms of eutrophication.
C. Climate change facilitates the introduction of invasive species.
D. Climate change accelerates propagation of invasive species and their negative impacts.
E. Species invasion leads to eutrophication.
F. Eutrophication leads to species invasion.

3.4.2 Ecosystem Categories and Scores

I consider six categories of ecosystems (I–VI) for analysis. These categories have been proposed to convert qualitative information into quantitative data on the basis of the six selected phenomena (A–F). This proposition is based on the categorization used by Dutta (2018).

Category I ecosystems are the ones in which any one of the six phenomena have taken place (A, B, C, D, E or F). Thus, there could be six different types of affected ecosystems in this category. So, this category has been assigned a score of 06 (Table 1).

In Category II ecosystems, any two out of the six phenomena have occurred. As calculated in MS Excel, the six phenomena can occur in 15 different combinations whenever any two phenomena are grouped together (A + B, A + C, A + D, A + E, A + F, B + C, B + D, B + E, B + F, C + D, C + E, C + F, D + E, D + F, E + F). Thus, there could be 15 different types of affected ecosystems in this category. So, this category has been assigned a score of 15. Similarly, the scores of the categories III, IV, V and VI have been found to be 20, 15, 06 and 01 respectively (Table 1).

Table 1 Scores obtained by the six categories of ecosystems considered

Category of ecosystem	Score	Chi-square test (among the scores)
I	06	$\chi^2 = 24.90$, df = 5, $p < 0.01$
II	15	
III	20	
IV	15	
V	06	
VI	01	

3.4.3 Statistical Analysis

Each category was considered as a variable and the corresponding score was considered as its value. Thus, there were six variables each of which had a particular value. Chi-square test was performed among the six values i.e. the scores of the six categories. A significant result ($\chi^2 = 24.90$, df = 5, $p < 0.01$) was obtained from this analysis (Table 1). The overall inter linkage among the issues has been depicted in Fig. 1.

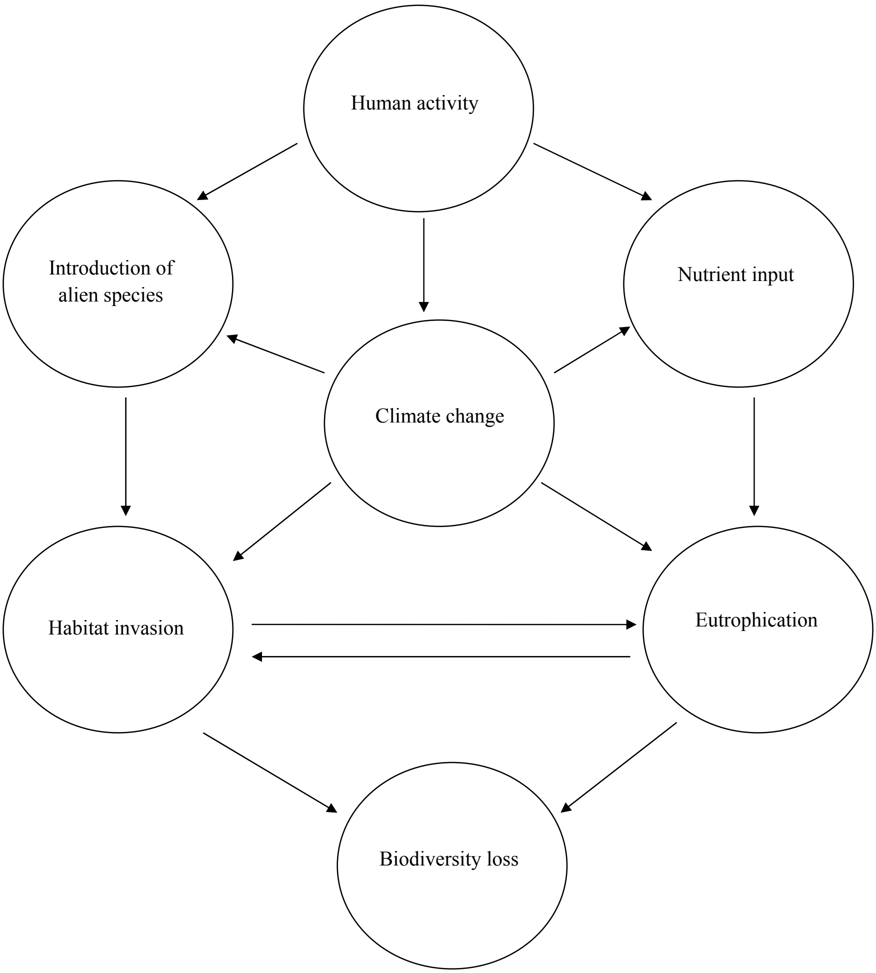

Fig. 1 The synergistic interlinkage among the climate change, eutrophication and habitat invasion

4 Discussion

The review brought to light some important mechanisms through which climate change facilitates species invasion and algal blooms. Climate change exerts leads to a number of primary, secondary and tertiary effects on habitats and the biology of organisms. This in turn intensifies these natural events up to the level at which they shape up as severe ecological problems. A closely related factor is human activity and its impact on ecosystems.

When the environment is changed, the outcome of competitive interactions among species is reversed. Thus, anthropogenic habitat alterations place native species at a competitive disadvantage with non-native species. When such changes trigger drastic changes, the environment can become entirely novel to the natives (Byers 2002). Anthropogenic activities, especially fishing have a synergistic effect and magnify the impact of climate-induced changes (Harley et al. 2006). Shipping is another important human activity that can exert tremendous impact of aquatic biodiversity because widespread interoceanic and transoceanic dispersal of aquatic non-native species take place via ballast water (Simkanin et al. 2009). Invasion probability for alien species that are spread by shipping is highest for intermediate geographic distances between donor and recipient ports (Seebens et al. 2013). Thus, cooperation among regional trading partners is essential to mitigate the problem of alien marine species (Bax et al. 2003).

It has been projected that biological invasions would be the main driver of biodiversity and ecosystem function loss in lakes in the 21st century. But the extent of future losses is difficult to quantify because most invasions are recent and depend upon other stressors (Bajer et al. 2016). It is also very difficult to explain the processes that determine the patterns of invasion ecology (Bajer et al. 2015). However, the most efficient invaders are more likely to belong to genera, which are not already present in the system (Ricciardi and Atkinson 2004). The pairing attributes of the invading species and the affected species are crucial to make simple predictions on the response of entire communities to species invasions locally (Thomsen et al. 2014). Important management options that could implemented to control such non natives include dispersal corridors that enable species to track environmental changes, translocation of species to new suitable habitats into which migration is not possible, and development of action plans for the early detection and eradication of new invasive species (Rahel et al. 2008) as well as management of vectors responsible for the introduction (Chen et al. 2017). In addition, studies that aim to predict future range shifts should consider trophic traits of aquatic non native species because such traits indicate multiple interacting mechanisms involved in the promotion of species invasions (McKnight et al. 2017). Physiological tolerance and propagule pressure can be used to make the best prediction about the spread of introduced fishes, whereas a measure of prior invasion success can be used to make the best prediction about their integration and impact (Marchetti et al. 2004). Information, education and public awareness are also required for the success of initiatives to prevent the spread of such fish species

(Elvira and Almodóvar 2001). Thus, it is evident that species invasion is a complex process that involves several different determinants that influence its expansion. Accordingly, different initiatives might be needed for management. Human activity is an important determinant that spreads alien species in multiple ways. Under several situations, human activity cannot be prevented. However, proper awareness would definitely encourage the public to carry out such activity in ways that do not accelerate negative effects on the aquatic environment.

From the literature survey, it can be summarized that climate change aids in the propagation of invasive species by facilitating their introduction, modifying habitats and increasing their vulnerability to invasion and favouring the growth and dominance of the invading species. These effects are not confined to any specific aquatic ecosystem or organism. The present review highlighted some important species that derive benefits from climate change. However, there are several other examples that can be cited from both fresh and marine waters. The review also brought to light the synergistic effects of climate change on eutrophication, which in turn can also intensify species invasion. This precisely demonstrates a situation in which the negative impact of one issue is magnified by another. In fact, there is a vicious cycle among the problems in which a positive feedback exists among anthropogenic impacts and the three problems.

Climate change results in greater water temperatures, decreased ice cover duration, alterations in the patterns of stream flow, greater salinization, and increased demand for water storage and conveyance structures. Consequently, fish culture facilities and water gardens are expanded to new areas. As a whole, such changes modify the pathways through which non native species enter aquatic systems (Rahel and Olden 2008). Changes triggered by global warming affect current patterns in oceans and in this way local dispersal mechanisms are altered. In addition, competitive interactions between non native and native species are changed due to the onset of new thermal optima and/or different carbonate chemistry (Occhipinti-Ambrogi 2007). Besides, several species are also shifting their distribution ranges towards higher latitudes due to climate change (CIESM 2008). The Mediterranean coastal areas could suffer from such impacts because their temperatures are expected to increase by at least 1–2.5 °C by the end of the 21st century (Di Carlo and Otero 2012). In order to mitigate the effects of climate change the establishment of marine protected areas and no-take reserves has been suggested because climatic disturbances are likely to cause lower negative impacts on populations and intact communities (Harley et al. 2006).

Algal blooms are natural phenomena (Anderson et al. 2002). The occurrence of such blooms has increased in marine and freshwater ecosystems due to physical, chemical and biological factors including climate changes and anthropogenic impacts (Sanseverino et al. 2016). In fact, climate change has been intensifying the symptoms of eutrophication in freshwaters (Jeppesen et al. 2010) and it is projected that global warming would increase cyanobacterial blooms in lakes (Wagner and Adrian 2009). As a whole, eutrophication and global warming enhance their proliferation and expansion (O'Neil et al. 2012). Vice versa, eutrophication is likely to promote climate change (Moss et al. 2011). This exemplifies the situation when a natural event becomes harmful after crossing a particular threshold under the influence of climate change and anthropogenic activity. Thus, in addition to devising control measures for eutrophication, steps must also be taken to control climate change and human activity or reduce their impacts. Nutrient enrichment is also brought about by certain invasive species (discussed earlier) and so this aspect should also be considered. This is because in the present time, ecosystems are exposed to multiple problems simultaneously. These problems are likely to exert a combined negative effect due to 'cause-effect' relationships among themselves.

Human activities have resulted in the dramatic alteration in the flux of growth-limiting nutrients from the landscape to receiving waters. Such nutrient inputs give rise to widespread negative effects upon the quality of surface waters (Smith 2003). Humans have changed the global Phospohorous budget and led to its accumulation in upland soils. Greater global build-up of soil Phospohorous has increased the severity and prevalence eutrophic waters. This impact can be can be controlled by reducing Phospohorous inputs to soil and minimizing the transport of Phospohorous from soils to aquatic ecosystems by increasing its sinks (Bennett et al. 2001). Periphytons are important tools to remove Phosphrous from lotic waters and wetlands. They play crucial roles in Phosphorous uptake as well as the deposition and filtering particulate Phosphrous from the water (Khan 2014). Water lettuce (*Pista stratiotes*) is also very efficient in removing nutrients from eutrophic waters because of its rapid growth and high biomass yield potential. But this efficiency is affected by temperature, water salinity and physiological limitations (Lu et al. 2010). However, this species can also well identified invader (Department of Agriculture and Fisheries, USA 2016). This once again indicates the inter linkage of ecological issues in the aquatic environment and how a suitable management method of one issue might lead to another. In general, while applying any mitigation measure, it must be ensured that the target problem is solved without triggering any other ecological problem. All the ecological effects of must be considered before adopting any mitigation measure.

Both freshwater and marine ecosystems respond positively to nutrient loading control efforts (Smith 2003). In order to control cyanobacterial dominance in lakes, it is necessary to reduce nutrient concentrations in a future warmer climate (Kosten et al. 2012). However, according to (Paerl et al. 2011), suggest that water quality managers should not only consider reductions in nutrient inputs, but also devise measures to break the synergy between nutrient loading and hydrologic regimes that aid the propagation of cyanobacteria by climate change. In fact, current mitigation and water management strategies mainly consider nutrient input and hydrologic controls. It is suggested that such measures should also incorporate the environmental effects of global warming (Paerl and Huisman 2009). Appropriate measures should be undertaken after proper evaluation and understanding ecological conditions. This is because a particular mitigation method suitable for a particular site might not be effective on another. At times, new measures are needed or a well established method might need to be modified before application. Besides, there could also be associated economic factors.

The statistically significant result of the chi-square analysis (Table 1) proved the importance of the overall synergistic effect of climate change on species invasion and eutrophication. In other words, this inter linkage should never be overlooked in aquatic ecosystems affected by either species invasion or eutrophication or both. This is because the difference between the negative impact of invasive species and/or eutrophication in ecosystems affected by climate change, and ecosystems not affected by climate change would not be negligible. Such a synergistic role of climate change is also evident in the terrestrial ecosystem (Dutta 2018).

Finally, it is concluded that several ecological and biological processes are linked with one another in the aquatic ecosystems. Consequently, the impacts of environmental problems that affect these processes are also interlinked. Therefore, when a particular problem magnifies, the related problem is also likely to intensify. In fact, one problem could also lead to an entirely new problem, as evident in the context of eutrophication and species invasion. Such linkages should be identified and assessed to understand their synergistic impacts and devise mitigation measures accordingly. This would lead to an effective conservation of aquatic biodiversity.

Conflict of Interest The authors declare no conflict of interest.

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Wildlife Conservation Perspective of Fringe Villagers and Their Socio-economic Dependency: A Case Study from Borail Wildlife Sanctuary, Assam, India

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Abstract Wildlife conservation perspective generally refers to the attitude of local people living in and around protected areas towards conservation of wild animals and plant species in their natural habitat. Socio-economic dependency of rural communities on natural resources very often for livelihood purposes leads to negative attitudes towards conservation. Rising human population, intensified land use, human pressure on animals, modification of natural resources, habitat fragmentation and lack of foresight in the implementation of policies have been linked with disputes affecting the rural communities living in and around protected areas and their socio-economic development. Information on perceptions and attitudes of local communities is important to identify proper management programmes and strategies that best suit the conservation of biodiversity alongside the socio-economic development of local communities dependent on forests for their livelihood. Borail Wildlife Sanctuary is the only wildlife sanctuary in the southern part of Assam. The sanctuary is important biologically as it supports the Cachar Tropical Evergreen Forest and many rare and unique species. In recent times, anthropogenic pressure on forest and wildlife is on the rise because of the increasing human population around the sanctuary. In

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the present study, conservation studies were undertaken among the fringe villagers of Borail Wildlife Sanctuary (i) to understand attitude and perception towards forest and wildlife conservation, and (ii) to assess their socio-economic dependency on forest and wildlife. The fringe villagers of Borail Wildlife Sanctuary were found to possess a positive attitude towards the sanctuary as a whole which is essential for participatory conservation and management programme in this protected area situated in the vulnerable eco-region of north east India. The dominance of utilitarian value among the local communities indicate towards their social and economic dependency on the Borail Wildlife Sanctuary, particularly for collecting firewood, constructing huts (*kutcha* houses), cultivation of beetle vine (*pan jhum*) etc. Acceleration of soil erosion and accentuation in the variability of rainfall distribution as a result of long term shifting cultivation in Borail Wildlife Sanctuary might be detrimental for conservation of wildlife and biodiversity. This necessitates sanctuary-community interaction for strengthening the sanctuary-community relationship in order to persuade the local communities to take up alternative forms of livelihood in order to protect the sanctuary. However, the local villagers were not willing to take part in the current conservation activities which may be attributed to their low level of education and lack of environmental awareness. The traditional beliefs of a section of fringe villagers particularly in protecting non-human primates and banyan trees hold key to participatory wildlife and biodiversity conservation programmes, which the government agencies, policymakers as well as non-governmental organizations might utilize for successful protected area management coupled with enhanced education and creation of awareness among local communities. Moreover, creation of wildlife corridors across the national highway might help save many wild animals of the Borail Wildlife Sanctuary (which is particularly rich in reptile biodiversity) from road kills by speeding vehicles.

Keywords Anthropogenic pressure · Land-use changes · Shifting cultivation · Livelihood issues · Protected area · Conservation attitude · Utilitarian value · Traditional conservation beliefs · Wildlife corridor · Sanctuary-community interaction

1 Introduction

Wildlife conservation perspective generally refers to the attitude of local people living in and around protected areas towards conservation of wild animals and plant species in their natural habitat. Attitudes play a major role in acceptance of environmental policies or management actions by the public at large, and conservationists in particular (Winter et al. 2005). Historically, there have been different views on functions of protected areas in relation to local residents. During the 1970s and 1980s, international organizations devoted to conservation of wildlife and biodiversity neither dealt with local community issues nor with the presence of indigenous or rural people inside or around protected areas (Chapin et al. 2004). In general, people living in close proximity to protected areas show a strong negative attitude towards wildlife (Newmark et al. 1994). Those who incur wildlife damage have more negative attitudes relative to those who incur fewer damages (Shibia 2010). Socio-economic dependency of rural communities on natural resources very often for livelihood purposes leads to negative attitudes towards conservation (Masozera 2002). In fact, the massive network of wildlife sanctuaries widely hailed as examples of successful conservation have often had a negative impact on the lives of the surrounding human population (Guha and Gadgil 1992). Moreover, rising human population, intensified land use (Ngure 1995), human pressure on animals, modification of natural resources, habitat fragmentation (Sukumar 1994) and lack of foresight in the implementation of policies have been linked with disputes affecting such rural communities and their socio-economic development. Information on perceptions and attitudes of local communities living in and around protected areas is important to identify proper management programmes and strategies that best suit the conservation of biodiversity alongside the socio-economic development of local communities dependent on forests for their livelihood (Heinen 1993; Infield and Namara 2001; Allendorf 2007; Kideghesho et al. 2007). This understanding is also vital for averting and/or resolving potential human-wildlife conflicts, which otherwise may threaten the success of any conservation initiative (De Boer and Baquete 1998; Webber et al. 2007). Therefore, wildlife and biodiversity conservation programmes need to actively involve the local communities including satisfying their cultural, social and political considerations in the environment (Newmark et al. 1994).

India's north eastern region harbours globally significant proportion of wild flora and fauna as it falls under the Indo-Burma as well as the Eastern Himalayas biodiversity hotspots. The tropical humid climate with average annual rainfall of 3383.50 mm and average humidity of 78% coupled with its unique geographical position as well as variable eco-climatic conditions, has blessed this area as one of the richest treasure-houses of floral and faunal wealth. Borail Wildlife Sanctuary is the only wildlife sanctuary in southern part of Assam. It consists of the North Cachar Reserve Forest and the Borail Reserve Forest which are classified as tropical moist evergreen and semi-evergreen forests. The sanctuary is important biologically as it supports the Cachar Tropical Evergreen Forest and many rare and unique species (Choudhury 1993). A number of tea estates are situated along the periphery of the sanctuary. In recent times, anthropogenic pressure on forest and wildlife is on the rise because of the increasing human population around the sanctuary. In the present study, conservation studies were undertaken among the fringe villagers of Borail Wildlife Sanctuary (i) to understand their attitude and perception towards forest and wildlife conservation, and (ii) to assess their socio-economic dependency on forest and wildlife.

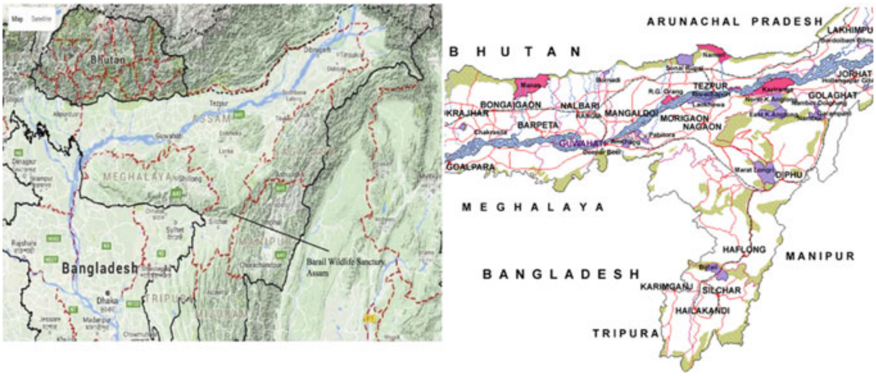

Fig. 1 Location of Borail Wildlife Sanctuary in southern Assam, India: **a** Satellite map from Google. **b** From Department of Environment & Forests, Government of Assam

2 Methodological Framework

2.1 Study Area

Borail Wildlife Sanctuary is located at low to mid elevation area of Borail Hill Range between 24° 58′–25° 5′ N latitude and 92° 46′–92° 52′ E longitude covering a total area of 326.24 km^2 (Fig. 1). The sanctuary is governed under two forest range offices namely, Udharbond and Kalain range offices. To the west lies the Narpuh Wildlife Sanctuary in Meghalaya, which is separated by Baleshwori river in Malidor. The Jatinga River divides the sanctuary into two blocks—West block and East lock. The Kalain river flows through the East block. To the northern side of Borail Wildlife Sanctuary lies the Dima Hasao district, which is completely degraded. Doloo river flows through the western boundary of the sanctuary. The sanctuary falls within the plains of Cachar district towards its southern side where the mighty Barak river flows, whereas the western and eastern sides are continuous hilly terrain. The plains beyond have large patches of tea gardens and paddy fields. The sanctuary is a continuous hill tract starting from Narpuh Wildlife Sanctuary, towards its western boundary.

2.2 Data Collection

Quantitative research method with closed-ended questionnaires was used. Data were gathered by surveying the habitat of six randomly selected villages adjoining the Borail wildlife Sanctuary in Cachar district of Assam. Selection of villages was done using random sampling calculator—Maruacherra Punji Part 1, Maruacherra Punji Part 2, Naraincherra, Damcherra Punji, Harincherra, and Jinghacherra. A total

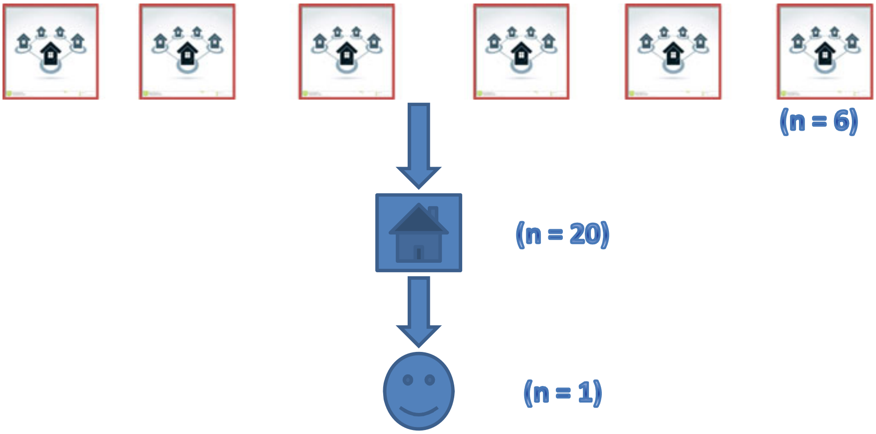

Fig. 2 Schematic representation of the survey

of 120 families were surveyed by taking 20 fringe villagers belonging to 20 families of each village (Fig. 2).

2.3 *Perception and Attitude*

Closed-ended questionnaires were prepared to study the perception and attitude of fringe villagers towards the sanctuary, for example, whether they liked the forest or not, the main reason behind their liking/disliking, restrictions imposed on local people towards undertaking activities inside the sanctuary, reasons for their entry into the sanctuary, their satisfaction/dissatisfaction with the ongoing conservation activity, their traditional belief for conserving wild animals and plant species, if any, including the impact of the national highway NH54-E that has come up recently bifurcating the sanctuary.

2.4 *Socio-economy*

Closed-ended questionnaires were prepared to obtain the socio-demographic and economic information from individual fringe villagers, such as religion, caste, number of family members per house, age, education, occupation, income from normal occupation, income from the sanctuary, average home garden area, livestock owned, fuel used for cooking, house pattern and family pattern.

The questions were translated into local languages based on the linguistic communities inhabiting the villages, i.e., Khasi, Bengali and tea tribe. Since most of the respondents were illiterate the questions were read and explained to the respondents and their responses were recorded in writing. Each questionnaire took approximately 20–30 minutes to complete.

2.5 Data Analysis

The population was classified into adult male (male above 18 years), adult female (female above 18 Years), minor male (boys above 1 year and below 18 years), minor female (girls above 1 year and below 18 years) and infants (below 1 year). The infants constitute 14.55% of the total population whereas minor males constitute 22.70%, minor females were 17.63%, adult males were 22.30% and adult females were 22.83% of total population. The scales' for restriction imposed in entering forest ranged from 1 to 5 in all the communities. Since the data were not normally distributed the discrete data were transformed to continuous data using Log transformation. Summarized and numerically coded survey data was placed in an MS Excel spreadsheet and data analysis was conducted. Descriptive statistics such as frequency table and percentages were used to analyze and report personal characteristics of the respondents while inferential statistics such as Chi square, Z-test and correlation analysis were employed to analyze the hypothesis of the study. Kruskal-Wallis Analysis of Variance (ANOVA) was used to test whether there were significant differences in community perceptions of conservation among the four communities. $P < 0.05$ were considered statistically significant.

3 Results

3.1 Perception and Attitude

Most of the fringe villagers (92.0%) possessed a positive attitude towards the sanctuary, although the utilitarian value was found to be dominant (48.73%) over aesthetic (21.84%) and naturalistic (29.41%) values ($\chi^2 = 13.73$, df = 2, $P < 0.05$) (Fig. 3). A large portion of fringe villagers (71.67%) were neither satisfied with the present conservation efforts in the sanctuary, nor were they (72.0%) willing to take part in any conservation activities. A small section (13.93%) of fringe villagers possessed traditional belief to protect non-human primates and banyan trees. A large number of fringe villagers (64.16%) considered the recently constructed road NH-54E to be positive. 43.0% fringe villagers were not aware of wild animals being killed by speeding vehicles, whereas 39.0% respondents had seen road kill of wild animals earlier and 18.0% individuals did not notice any such thing ($\chi^2 = 12.43$, df = 2, $P < 0.05$) (Fig. 4). Among various wild animals, reptiles (40.90%) were found to be

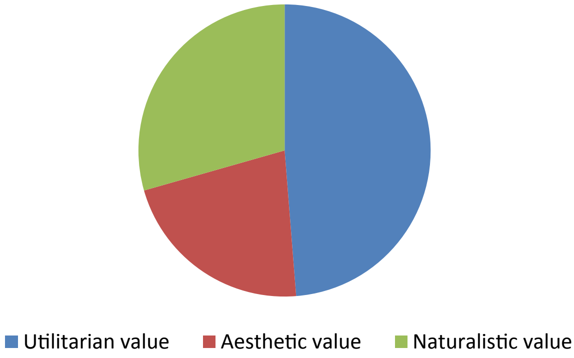

Fig. 3 Values held by fringe villagers towards Borail Wildlife Sanctuary

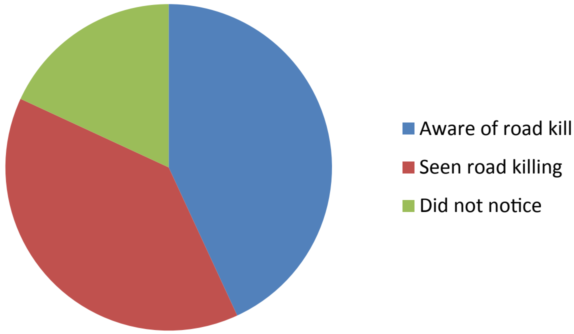

Fig. 4 Awareness of fringe villagers towards road killing of wild animals by speeding vehicles in Borail Wildlife Sanctuary

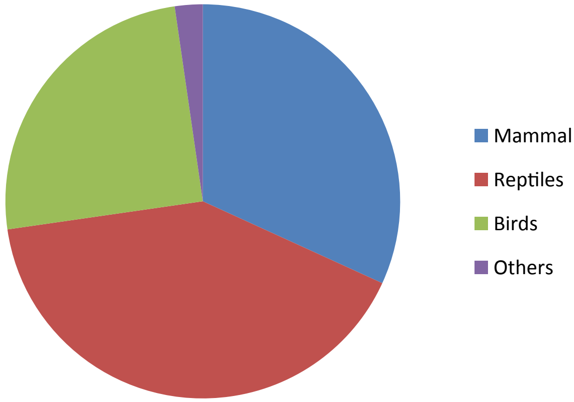

Fig. 5 Classes of wild animals killed in Borail Wildlife Sanctuary by speeding vehicles while crossing national highway

killed frequently by speeding vehicles in comparison to mammals (31.81%), birds (25.0%), and others (0.02%) ($\chi^2 = 3.59$, df = 3, $P < 0.05$) (Fig. 5).

3.2 Socio-economy

The study revealed that the village population around the Borail Wildlife Sanctuary belonged to three religious communities—Christians (54.0%), Hindus (39.0%) and Muslims (7.0%). Fringe villagers living around the Sanctuary belonged to the five castes predominated by scheduled tribes (ST—55.0%) followed by tea tribes (36.0%), scheduled caste (SC—1.0%), general (7.0%) and other backward caste (OBC—1.0%). Their sex ratio was 976.61 adult females per 1000 adult males, and 776.47 minor females per 1000 minor males. The population of minor females was significantly lower than minor males in the fringe villages ($\chi^2 = 4.78$, df = 1, $P < 0.05$) (Fig. 6). Also, nuclear family pattern was found to be predominant among the fringe villagers having a ratio of 63:17 nuclear:joint families ($X^2 = 19.08$, df = 1, $P < 0.05$). Huts (or *kutcha* houses) were significantly higher than the permanent dwellings (or *pucca* houses), with a ratio of 73:47 ($X^2 = 5.64$, df = 1, $P < 0.05$). Education of fringe villagers was mostly below the secondary level, with shifting cultivation of beetle vine (locally known as *pan jhum*) being the predominant occupation (39.30%) in comparison to stone quarry workers (28.82%), small industry workers (13.97%) and daily wage labourers (17.90%) (Fig. 7). Almost all the fringe villagers (99%) used firewood collected from the sanctuary as fuel wood barring few (1%) who rely on kerosene. Their monthly income ranged between 1900 and

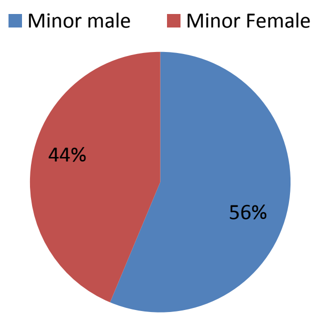

Fig. 6 Proportion of minor females and minor males among fringe villagers of Borail Wildlife Sanctuary showing a skewed sex ratio

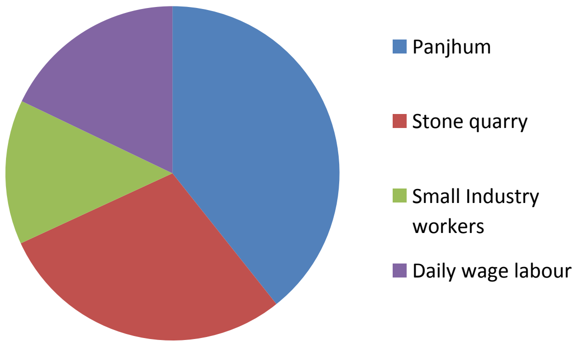

Fig. 7 Major occupation of fringe villagers of Borail Wildlife Sanctuary

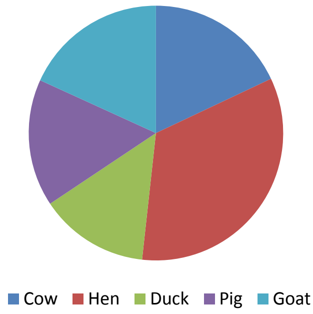

Fig. 8 Livestock rearing pattern among fringe villagers of Borail Wildlife Sanctuary

10,500 Indian Rupees (INR) with the average monthly family income being INR 4788.79. Monthly income did not differ among the villages. Rearing of livestock, for example, cow (18.0%), goat (18.0%), hen (34.0%), duck (14.0%) and pig (16.0%) were common among the fringe villagers with poultry farming being predominant ($\chi^2 = 170.57$, df = 5, $P < 0.05$) (Fig. 8).

4 Discussion

4.1 *Perception and Attitude*

The perception and attitudinal studies of fringe villagers revealed that they considered the Borail Wildlife Sanctuary to be important. Attitudes in conservation of wildlife can be divided into nine types: ecologistic, naturalistic, humanistic, moralistic, scientific, aesthetic, utilitarian, dominionistic, and negativistic (Kellert and Westervelt 1983). Among the fringe villagers of Borail Wildlife Sanctuary, utilitarian value was found to be dominant in comparison to aesthetic and naturalistic values as the local communities derived material benefits from the sanctuary. Similar findings were reported from the Reserve Forests of Kodagu district in Karnataka, India where 89% of the respondents expressed a positive attitude towards the reserve forests although the inhabitants of coffee plantations more frequently expressed positive attitudes toward the reserved forests (Macura et al. 2011). Another study in Gashakan Gumti National Park (GGNP) in Nigeria showed that the communities had positive attitude towards conservation. However the reason for the positive attitude of the communities around GGNP was economic benefits derived from the park (Ogunjinmi et al. 2012). A study in Parsa Wildlife Reserve, Nepal reported the reason for liking the reserve by the local people was due to the role of protected areas in biodiversity conservation, generating opportunities for employment, tourism and business, provisions for natural resource use, security and moral attachment to the place (Thapa 2016).

In the present study, a vast majority of villagers were not satisfied with the current conservation and management activities of the Borail Wildlife Sanctuary. Similar findings were reported from Kakamega forest in Kenya, where local people were not satisfied with the protectionist approach (Guthiga et al. 2008). In Borail Wildlife Sanctuary, a small portion of the local communities practised a religious belief of protecting non-human primates and banyan trees (*Ficus benghalensis*), which is similar to that reported in the worship of python in West Bengal kingdom where there was evidence that the reptile was associated with success in war (Deb and Malhotra 2001). In India, traditions and cultural or religious attitudes towards wild animals often make local people more tolerant towards wildlife, despite the damage to crops and livestock they cause (Imam et al. 2002).

A large number of fringe villagers considered the recently constructed road i.e. NH-54E that bisected the sanctuary to be good for them particularly for availing better transport and communication. However, majority of the locals were not aware of the road kill of wild animals by speeding of vehicles on the highway. This NH-54E seems to be one of the major threats that the Borail Wildlife Sanctuary faces particularly because it bisects the sanctuary which adversely affects the crossing of wild animals. There are proposals to upgrade this road to a four lane highway which is likely to increase the frequency of traffic thereby impacting the movement of wild animals as there is no established wildlife corridor. This necessitates immediate mitigation measures in order to save thousands of wild animals including some endangered species from possible road kills. Similar to our results, another study from Sathyamangalam Wildlife Sanctuary in Tamil Nadu where another national highway NH 209 bisects the sanctuary reported that the local communities were partially aware of its impacts on wildlife (Lakshminarayanan and Mohan Raj 2015).

Major roads passing through forests cause irreversible physical disturbances to the forest, and act as barriers to flora and fauna, curtailing free physical movement and even genetic flow. Roads also have other undesirable deleterious consequences to forest ecology such as weed proliferation, biotic pressure due to littering and others. Road and highway construction affects wildlife through the direct loss and fragmentation of habitat and by disrupting animal movement and dispersal (Trombulak and Frissell 2000). Numerous studies from India have demonstrated the ill effects of major roads on survival prospects of wildlife (Das et al. 2007; Seshadri et al. 2009; Baskaran and Boominathan 2010). One of the serious direct threats posed by roads to conservation is wildlife mortality as a result of collisions with speeding vehicles. The present study also revealed that mortality rate of reptiles was more in Borail Wildlife Sanctuary as compared to other wild animals by speeding vehicles on road. Similar findings were noted from the Pench Tiger reserve and Satpura Tiger reserve where mammals and birds seemed particularly vulnerable (Fellows et al. 2015).

4.2 Socio-economy

The findings of the study revealed that majority of the fringe villagers of the Borail Wildlife Sanctuary were Christians, followed by Hindus and Muslims. Furthermore, scheduled tribes (ST) were predominant over other castes, such as tea tribes, scheduled caste (SC), general and other backward caste (OBC). The proportion of minor females was significantly lower than that of minor males in the population which is a cause for serious concern as there have been fears of intrauterine fetal death adopted by several local communities in some parts of India. From the fringe villages of Ranga, Kakoi and Dulung reserve forests of Lakhimpur district, Assam, similar findings were reported where the population of males was higher than the female population and the villagers belonged to Hindu religion followed by Christians and Muslims. Majority of the population were of OBC category followed by SC and ST (Bhuyan 2015).

Furthermore, huts (or *kutcha* houses) were predominantly higher than the permanent dwellings (or *pucca* houses) among the fringe villagers of Borail Wildlife Sanctuary. The fringe villagers also depended on the forest resources for meeting their daily requirements primarily as source of firewood which they utilized as fuel.

Local people's knowledge about natural resources conservation are influenced by education and awareness programmes, services and benefits local people receive from conservation related projects. Education of fringe villagers of Borail Wildlife Sanctuary was mostly below the secondary level, as evident from the present study. This indicates that there is an urgent need to enhance education and take up awareness programmes, and strengthen law enforcement for improving the overall sanctuary-community relationship. Existing education and awareness programmes, if improved, are likely to have a positive impact on local people's knowledge about natural resources conservation as education and awareness are important tools in motivating people to develop or reinforce positive perceptions about biodiversity conservation. The findings from our study suggested that conservation in the Borail Wildlife Sanctuary heavily relied on local communities due to their perceived benefits from the sanctuary. Nielsen (2003) noted that if the risk perceived by local community is too high in relation to the potential benefits of violating protected areas regulations, then compliance is likely to be enhanced.

In the present study, the local communities largely used the Sanctuary for cultivation of beetle vine (*pan jhum*) which was their major occupation. This is a type of shifting cultivation and is an important form of primitive agricultural land use. In this system forest area is cleared by slash and burn techniques. There are various effects of shifting cultivation with large scale deforestation leading to undesirable ecological imbalance. Since the hill tops particularly the catchment areas are the source of water, deforestation in the hills often lead to elimination of the sources of water which increases the run-off due to consequent inability of the soil to retain the water. The clearance of forest causes deforestation which accelerates soil erosion and accentuates the variability in rainfall distribution. Burning of such land can be considered as one of the worst impact on climate because it creates scope of high rate of soil erosion and structural stability of soil is impacted by runoff and winds. The availability of water in the soil for the crop production also decreases which is vulnerable to climatic variation. Thus, shifting cultivation in varied forms is destructive to the environment because forest areas are being converted to agriculture through such practices thereby diminishing the area under primary forest (Barkakoti 1990). Similar to the results of the present study, in Uttar Pradesh's Suhelwa Wildlife Sanctuary 39.2% of people lived in *kutcha* houses, while only 26.2% of them had complete *pucca* houses (Jaiswal and Bhattacharya 2013). In Bumdeling Wildlife Sanctuary of Bhutan the local communities were found to utilize forest resources to meet their daily requirements (Wangyal 2012). Similar was the case in rural communities around Manombo Forest of Madagascar where firewood formed the primary (often the only) fuel available for domestic cooking and local communities harvested firewood illegally from the protected Manombo areas (Abram 2008). The use of trees in terms of shade protection from heat and sand was reported by the fringe villagers of Kosti province in central Sudan (Kobbail 2012). They also used trees as a source of charcoal as well as for fodder, fencing and source of fruits.

The level of education of fringe villagers of Barail Wildlife Sanctuary was below the secondary school. Similar findings were reported from a protected area of Retezat National Park in Romania where less than 30% of residents had any sort of college education. Another recent study from Parsa Wildlife Reserve in Nepal also reported the majority of villagers below secondary level of education, 34% of the respondents being illiterate (Thapa 2016).

A large number of villagers living in the fringe areas of Barail Wildlife Sanctuary practiced poultry farming which was significantly higher in comparison to piggery, duckery and dairy farming. However, livestock rearing did not have any significant correlation with conservation perceptions of local people, as reported from the Umfurudzi Park, Gonarezhou National Park, Matusadona National Park and Cawston Ranch of Zimbabwe (Mutanga et al. 2015). On the other hand, fringe villagers of Central Kenya with herds of livestock had a more negative perception towards protected areas and are often less supportive of conservation than those with fewer livestock (Gadd 2005; Romanach et al. 2007).

5 Conclusions

The fringe villagers of Borail Wildlife Sanctuary possessed a positive attitude towards the sanctuary as a whole which is essential for participatory conservation and management programme in this protected area situated in the vulnerable eco-region of north east India. The dominance of utilitarian value among the local communities indicate towards their social and economic dependency on the Borail Wildlife Sanctuary, particularly for collecting firewood, constructing huts (*kutcha* houses), cultivation of beetle vine (*pan jhum*) etc. Although this primitive shifting agricultural land use is associated with large scale deforestation leading to undesirable ecological imbalance which is critical for this sensitive hilly landscape. Acceleration of soil erosion and accentuation in the variability of rainfall distribution as a result of long term shifting cultivation in Borail Wildlife Sanctuary might be detrimental for conservation of wildlife and biodiversity. This necessitates sanctuary-community interaction for strengthening the sanctuary-community relationship in order to persuade the local communities to take up alternative forms of livelihood in order to protect the sanctuary. However, the local villagers were not willing to take part in the conservation activities which may be attributed to their low level of education and lack of environmental awareness. The traditional beliefs of a section of fringe villagers particularly in protecting non-human primates and banyan trees hold key to participatory wildlife and biodiversity conservation programmes, which the government agencies, policymakers as well as non-governmental organizations might utilize for successful protected area management coupled with enhanced education and creation of awareness among local communities. Moreover, creation of wildlife corridors across the national highway might help save many wild animals of the Borail Wildlife Sanctuary (which is rich in reptile biodiversity) from road kills by speeding vehicles. In conclusion, there is an urgent need to enhance environmental education and take up awareness programmes about conservation of natural resources among the local communities as they may play a crucial primary role in sustainable use of bioresources. Community based participatory conservation and management practices may help reduce the utilitarian approach and enhance the naturalistic value of wildlife and forests among the fringe villagers of Borail Wildlife Sanctuary.

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Carbon Sequestration Potential of Trees in Kuvempu University Campus Forest Area, Western Ghats, Karnataka

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Abstract Assessing carbon sequestration by measuring above ground and below ground biomass with non destructive method is globally acknowledged. The studies from forest ecosystem have made a significant contribution in quantifying carbon stock. This type of study has now gaining importance in urban ecosystems. Most of the institutions and universities have natural forest and manmade plantations are now assessing carbon stocks in India and elsewhere. In the present study Kuvempu university campus which is a part of Central Western Ghats was assessed. The total area of the campus covers 326.21 acres with dry deciduous forest of Bhadra tiger reserve. A total of 5596 individuals were recorded with a carbon stock of 457.0 t ha^{-1} and the dominant *Terminalia paniculata* contributed a total of 13% of carbon stock. The storing capacity varies with species diversity, disturbance gradient and phenology. This pilot study has made an attempt in advertising the present area in global carbon stock assessment. Therefore, every educational institutions/universities can easily contribute to global CO_2 mitigation by restoring the native species in their campus and even it supports biodiversity and helps in future long term monitoring.

Keywords Biomass · Carbon stock · Trees · Diversity · Tropical forest · Dry deciduous forest · Western Ghats

1 Introduction

Global warming and associated climate change is negatively impacting humans and almost all ecosystems on the earth. The main cause of this change is rapid increase in greenhouse gases (Gupta and Bhatt 2019).

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The carbon dioxide level has been continuously increasing from a preindustrial period by 279 ppm through 393.84 ppm in 2012 to 395.15 ppm in August 2013 and the projected concentration of CO_2 in 2100 will range from 540 to 970 ppm and this will lead to increase in temperature by 1.8–4 °C. A rise in the global mean temperature of 0.74 °C has been recorded. Consequently, the climatologists are calling for a pressing action to hold back global warming (Sundarapandian et al. 2013).

Global warming includes rise in temperature over land and sea surface, melting of glaciers and ice sheets, rise in sea level, ocean acidification, change in flowering and fruiting phenology of plants, shift in movement of fishes and animals. Further, new disastrous diseases have been outbreak due to global warming and climate change (Pragasan 2016).

Carbon sequestration is a natural removal of carbon from atmosphere by plants and soil depositing it in the reservoir. It has also been defined as any of the several processes for removal of excess carbon dioxide (CO_2) from atmosphere in an effort to moderate global warming (Subramaniyan et al. 2017). It is the controlled disposal or storage of carbon compounds to prevent their release into the environment and it is sequestered by plants during photosynthesis process which is done by the leaves that helps in extracting the carbon from atmosphere.

One of the major environmental issues of this century is Global warming (Jithila et al. 2018). Plant vegetations store carbon in the form of live biomass till their lifespan. The trees perform important ecological function of reducing environmental pollution through sequestering carbon. Trees and their canopies provide a freezing effect on microclimate specifically by shading the floor and obliquely through transpiration.

All living organism has carbon and it is the major structural block for life on earth. Carbon exists in various forms, predominately as plant biomass, soil organic matter, carbon dioxide (CO_2) in the atmosphere. There is an everlasting carbon cycle in which carbon is being sequestered on the earth and release back into the atmosphere continuously. It is argued that the accelerating accumulation of greenhouse gases, particularly carbon dioxide (CO_2), in the atmosphere from human activities such as reducing amount of forest cover, increasing the amount and variety of chemicals released into the atmosphere, and intensive farming, is driving climate change. Some of these changes have decreased the capacity of the environment to support some life forms (Jaiswal et al. 2014).

Biomass is the organic matter of trees and is the source of all other productivity in the forest and the biomass can be used to: (a) to determine energy fixation in forest, (b) to measure increment in forest yield, growth, or productivity and (c) assess changes in forest structure (Devi and Yadava 2015) and quantity of biomass in a forest determines the potential amount of the carbon that can be added to atmosphere or sequestered on the land with the intense focus on the increasing levels of atmospheric CO_2 and the potential for global climate change, there is an urgent need to assess the possibility of managing ecosystem to sequester and store carbon (Borah et al. 2013).

Carbon sequestration in growing forests is known to be a cost effective option for mitigation of global warming and global climatic change. Indian forest is sequestering more than 116 million tons of CO_2 per year which is equal to 32 million of carbon sequestration, contributes to reduce atmospheric carbon of the globe (Marak and Khare 2017). And this can be quantified to assess the magnitude and role of urban forests in relation to climate change (Arya et al. 2018). Although the extent and impact of increasing atmospheric CO_2 on climate change are unknown and relatively controversial, the Intergovernmental Panel on Climate Change (IPCC) reached an agreement in December, 1997, in Kyoto, Japan, to reduce greenhouse gas emissions. Under the Kyoto Protocol, the U.S. is requested to reduce net emissions of CO_2, NH_4, and N_2O by 7% below 1990 levels by 2008–2012. Sequestration of carbon could be counted as well as reductions in emissions (Williams et al. 2000).

The C-stock in the wooded land of Nepal (44.74% of the total area of the country) has recorded the peak. It is only due to the introduction of community forestry which started in the late 1970s, and has reversed the deforestation and forest degradation rates 9:10. Such forests act as a major source of C-sink storing about 20% of the total C-stock (Bhatta et al. 2018). According to the India State of Forest Report, 2017 total carbon stock in forests of India in 2017 is 7082 million tons. It has also reported that the annual increase in carbon stock is 19 million tons (Mishra and Prasad 2018).

Tropical forests play an important role in the global carbon (C) cycle and sequestering carbon dioxide to mitigate climate change. They are major sinks for atmospheric carbon, accounting for 50% of the above ground carbon in the vegetation (Hunter et al. 2013). The increased emissions of greenhouse gases have negatively impact on the climate, through various ecological imbalances. Comparatively, Carbon dioxide is most potent green house gas. Perhaps, the only possible way to reduce the level of carbon dioxide in the atmosphere is to maintain rich plant diversity in forest area, agricultural fields, urban areas and vacant lands.

In recent years the role of urban trees and parks in reducing levels of carbon dioxide and other greenhouse gases in the atmosphere has been identified as an additional benefit. Urban trees can reduce the levels of atmospheric CO_2 through sequestration and reducing CO_2 emissions by conserving energy used for heating and cooling (Devi 2017).

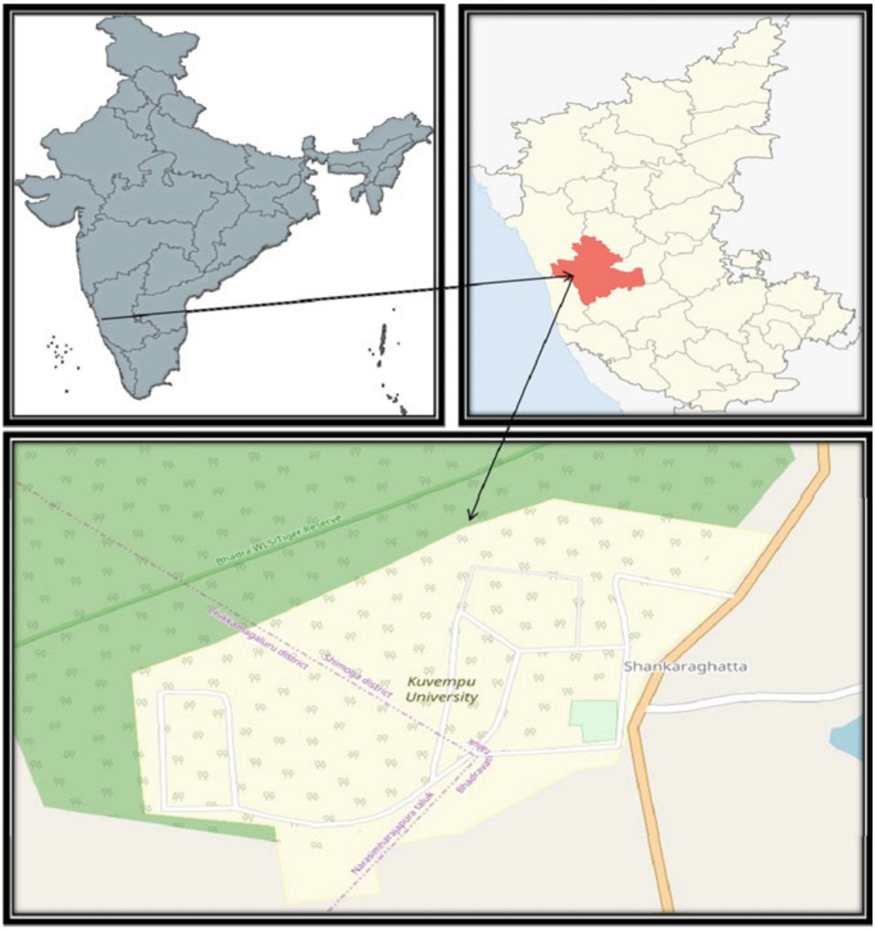
But to know the actual reason behind it we need some permanent plots not only to measure diversity of species like (mortality, natality and regeneration success) the carbon carrying capacity varies depending on the forest structure and type. The earlier studies like the floristic diversity of Bhadra wildlife sanctuary (Krishnamurthy et al. 2009, 2010) as well as phenological studies (Nanda et al. 2010, 2014) and Kuvempu University campus floristic diversity are documented (Narayana et al. 2017).

The present study addressed carbon stock among both forest trees and introduced species of the Kuvempu university campus. This may be attributed to the either temporary or permanent changes in structure, density (canopy closure, canopy quality, tree density, biomass density and fragmentation), and species composition.

2 Study Area

The focal area of the study is Kuvempu university campus which is located in the Central Western Ghats region, Karnataka, India. It is situated 23 km south of Bhadravathi, 38 km northwest of Chikkamagaluru, 24 km south-east of Shimoga and 4 km north of Bhadra reservoir. The Geographical position of the study area is $13^\circ\ 42^{1}\ 22^{11}$ N and $75^\circ\ 30^{1}\ 2^{11}$ E with a MSL (Mean Sea Level) of 680–720 m. The average temperature ranges between 18 and 36 °C and the relative humidity ranges between 60 and 75%. The study area receives an average rainfall of about 1000-mm/year, highest in the month of June, July and August during the onset of South-West monsoon.

The campus area is covered with dry deciduous forest of Bhadra Tiger reserve. It is a steadily emerging secondary forest because most of the trees age ranges between 15 and 35 years only. The total area of campus covers 326.21 acres. The campus has varied habitats like undulated hilly terrain, manmade wetlands, bamboo thickets, deciduous forests, monoculture plantations. The institutional management promoted avenue plantation every year from the date of establishment of University during various occasion which makes contribution for campus habitat for having a combination of both natural wild native and planted avenue trees. Hence the carbon study in the institution helps to know the sequestration potential of both natural forest and planted vegetation and in turn unknowingly throws a light on awareness to other institutions of the world to take part in mitigating atmospheric carbon emissions just by maintaining vegetation cover around their institutions wherever achievable. It is economically feasible too for every Colleges, Institutions and Universities and there by a step forward in lowering carbon emissions locally and globally.



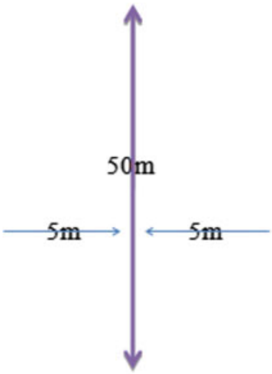
Map Source: Wikimedia Commons & Open Street Map

3 Materials and Method

The carbon sequestration study was undertaken to check the Total Carbon Stock (TCS) of the campus wild trees and as well as planted avenue trees. The floras irrespective of their growth form contribute to the carbon sequestration but it is also true that comparatively matured trees contribute more to carbon sequestration. Apart from vegetation, oceans are the greatest sink for carbon emissions. Unfortunately, the management of carbon sequestration by oceans is not there in the hands of human but better supervision of natural forest and promoting planting avenue trees in the vacant land around institutions can easily lower the amounts of atmospheric carbon emissions through sequestration. Hence the quantification of carbon sequestration by trees is essential both globally and locally in the perspective of combating climate change.

The study was carried out for a time period of 9 months from September 2018 to May 2019. A non-destructive method was followed on the basis of DBH (Diameter at breast height). Quantitative floristic inventories based on small sized permanent plots (1–2 ha) have been used in recent years to characterize the vegetation in different tropical forests by documenting their structure, composition and diversity. Here the line transact of 50 m × 5 m × 5 m were used to record and locate the trees. The DBH of each trees are documented and measured using measuring tape (CRATER, 30 m).

Above Ground Biomass (AGB), Below Ground Biomass (BGB) and Total Biomass (TB) of the different tree species were calculated using allometric equations developed by Brown et al. (1989), MacDicken (1997), Takimoto et al. (2008), Khan (2013) and Sundarapandian et al. (2014a, b).



4 Results

A total of 5596 individuals were recorded with a carbon stock of 457.0 t ha^{-1}. A major species composition was *Terminalia paniculata* (Roth) with 1455 individuals having 600.36 t ha^{-1} of carbon stock. The other dominant species *Eucalyptus tereticornis* Sm., *Santalum album* (L.) *Syzygium cumini* (L.) Skeels and *Annona reticulata* L, is 18.05 t ha^{-1}, 9.97 t ha^{-1}, 2.37 t ha^{-1} and 0.96 t ha^{-1} respectively but *Eucalyptus tereticornis* Sm & *Annona reticulata* L are the cultivated species which shows the importance of tree cultivation in mitigating carbon emissions.

The total carbon stock of the wild species dominated the contribution with 415.72 t ha^{-1} tons, where as cultivated species shows 41.28 t ha^{-1} of total carbon stock. The fast growing *Albizia saman* (Jacq.) Merr is cultivated as an avenue tree in the campus contributed 0.70 t ha^{-1} with only 25 individuals and *Ficus benghalensis* L. with only 11 individuals contributed 0.34 t ha^{-1} because of the higher DBH compared to other trees.

5 Discussions

In the recent past, the rise in the atmospheric concentration of carbon dioxide leading to global warming and climate change has attained immediate global concern. A few studies have been carried out so far prior to the urgent need for quantifying the forest carbon stock for better monitoring and management of the forest biomass carbon.

The carbon stock of 457.0 t ha^{-1} in the present study varies with other university campus carbon stock studies. Carbon sequestration by trees in Bangalore University campus have come up with 200.931 t ha^{-1} of carbon in 449.74 ha of campus area (Nandini et al. 2017), The total carbon stock inclusive of both above ground and below ground of all adult trees in the Pondicherry University campus was 2590.48 Mg (8.7 Mg C/ha) of 297 ha and the highest carbon stock value was observed in *Acacia auriculiformis*. (Sundarapandian et al. 2014a, b).

Total carbon stock sequestered by the Eucalyptus plantation and mixed species plantation was 27.72 and 22.25 t ha^{-1}, covering 2.5 ha and 2 ha area, respectively in the Bharathiar University campus at Coimbatore (Pragasan and Karthick 2013). The study was conducted in eight selected sample plots of the region, each with an area of 0.1 hectare in the tropical dry forest of the Chinnar Wildlife Sanctuary of Kerala located in the Southern Western Ghats, the average biomass and carbon density of the vegetation were 64.13 t ha^{-1} and 30.46 t-C ha^{-1} (Padmakumar et al. 2018). According to Murphy and Lugo (1986), the above ground carbon density in tropical dry forest varies between 14 and 123 t-C ha^{-1}.

In our study, the dominated *Terminalia paniculata* Roth contributed a total of 13% of carbon stock. This is due to high number of individuals. If large number of dominant tree species is under matured (low DBH), the less contribution to total carbon stock, even though the species is dominant in the study area. Chaturvedi et al. (2011) reported a carbon density ranging from 15.6 to 151 t-C ha^{-1} in tropical dry forests of India. Even though the above ground biomass carbon (AGBC) obtained in the present study is well within the limits of tropical dry forests, the results obtained are comparatively lower than the values reported in other tropical dry forest of India and elsewhere (Navar 2009).

Forests are among the most productive terrestrial ecosystems and attractive for climate change mitigation (Nabuurs et al. 2007). Exchange of carbon between forests and the atmosphere is being influenced by natural and anthropogenic disturbances. Understanding and quantifying the impacts of disturbances are prerequisites to selecting forest management options aimed at enhancing carbon sinks and reducing carbon sources, while maintaining other ecological, social, and economic benefits of the forest (Black et al. 2008) as disturbance was the primary mechanism that changes ecosystems from carbon sinks to sources based on Fluxnet synthesis (Baldocchi 2008).

Greater development of the understory and small trees (dbh $\leq$ 30 cm) in forest is a very important component of above ground biomass. Furthermore, these main groups will have great potential for sequestration in the future if the area is managed appropriately. As per the present study the above ground carbon storage of forest (457.0 t ha^{-1}) which is higher than other forests in India (Ravindranath 2007). Compared to studies in neighbouring countries, our results were fairly more to the natural forests in Indonesia (161.00–300.00 Mg ha^{-1}, Lasco 2002). Hence these kinds of carbon stock inventorying studies need long term observation for mitigation and policy interventions.

6 Conclusion

Carbon sequestration (carbon capture and storage) is one of the most important methods to understand the carbon induced climate change of solving the global climate issue. However, there is no single feasible solution. In order to know the effects of climate change, the carbon capture and storage study is essential. In this connection, trees play a very important role in mitigating atmospheric carbon dioxide levels. So that there is no more carbon being released into the atmosphere within it effects to the global warming. Furthermore, organic methods of farming, afforestation are the most effective eco-friendly methods of restoring natural ecosystem that was existed before industrialization with less carbon load in the atmosphere.

The present study reveals that the university campus contains rich natural tree species diversity with greater potential of carbon stock, as similar to the natural tropical dry forests. Additional research efforts are also needed to determine the extent of disturbance in the coming years and this base data will serve as major reference for future research in carbon density and diversity studies. Finally, the study concludes that diversified vegetation with higher DBH values indicate higher the load of carbon capture. Conservation of natural forest, as well as planting avenue trees can mitigate atmospheric carbon more potentially. Therefore, every institution can easily contribute to global CO_2 mitigation by planting diversified vegetations in their campus areas and even it supports biodiversity.

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Biodiversity and Conservation: India's Panoramic View

Leepica Kapoor and S. Usha

Abstract India is a mega diverse country and is known for its prodigious biodiversity encompassing varied floral and faunal species, terrestrial and aquatic ecosystems and rich agricultural and genetic diversity. However, factors like hotspots, extinction of species, changes in the climatic conditions, adverse effects of pollution, decline of traditional knowledge and alien invasive species are a threat to India's Biodiversity. Effective measures have been taken by formulation of legislative and national policies in line with NBSAP (National Biodiversity Strategies and Action Plan) stated under the Convention on Biological Diversity. The implementation of these measures is supervised from grass root level to national level to combat the biodiversity loss. There are several success stories which highlight the initiatives taken up towards safeguarding and enriching India's rich biodiversity of which two case studies have been discussed in this chapter.

Keywords Mega diversity · Ecosystems · Species · Biodiversity loss · Conservation · National policies · Case studies

1 Introduction

Biodiversity encompasses variability "in" species, "between" species and "among" ecosystems. A study of biodiversity helps us to measure the health of a biological system by evaluating the diversification it offers at four levels; species, genetics, ecosystem and functional diversity. Healthy ecosystems are characterized by existence of multiple species and supports growth and reproduction of its components. Genetic diversity within species promotes adaptation to varied environments, protection from threats, growth and development in ever changing surroundings (Adom

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N. Roy et al. (eds.), *Socio-economic and Eco-biological Dimensions in Resource use and Conservation*, Environmental Science and Engineering,
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et al. 2019). Along with its umpteen number of other benefits, biodiversity nurtures ecosystem services and promotes sustainable development. It is an asset to a country's economy as several components of biodiversity like fisheries, agriculture, genetic diversity among floral and faunal species, medicinal plants and traditional knowledge contribute to the green economic development therefore conservation of biodiversity is essential for achieving sustainable development.

2 Mega Diverse Countries

World' s biologically rich and wealthiest nations have been recognized by Conservation International, 1998 as "Megadiverse" based on the criteria of having a minimum of 5000 species of endemic plants and encompassing marine ecosystems. The list of megadiverse countries ranges from industrialized countries like Australia and United States of America to emerging countries like China, India, Brazil, Mexico, Malaysia, South Africa, Philippines and developing nations like Congo, Ecuador, Colombia, Madagascar, Indonesia, Papua New Guinea, Venezuela and Peru. However most of these nations are facing several threats (Tilman et al. 2017) as the escalating population rates and the resultant human activity, climatic changes, pollution, industrialization, urbanization, land degradation and invasive species affect the natural habitat and lead to misuse and exploitation of ecosystems (terrestrial, aquatic and marine ecosystems). Therefore action at this point is critical as the ecosystems on Earth are facing a blow by 6th mass extinction of its species. As per the IPBES (Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services) report, 2019, more than a million floral and faunal species are at the risk of being extinct. Effective policies and strategies under the umbrella of CBD in line with its Aichi targets 2011–2020 promotes several initiatives and policies for biodiversity conservation globally. As a continuous effort towards protecting our ecosystems, CBD plans to initiate a post-2020 global biodiversity framework in its efforts towards achieving the vision for 2050: "Living in harmony with Nature".

3 India's Biodiversity Framework

India, being a megadiverse country, has immense diversification in species and ecosystems contributing to its biological wealth along with its dynamic cultural heritage consisting of 4635 ethnic communities who are in harmony with nature and have protected it for centuries. Conservation of biodiversity is a national priority for India as it provides a plethora of raw material, produce and amenities essential for survival and support the livelihood of millions of people, thereby improving their socio-economic status and leading to sustainable development.

3.1 Variety of Floral and Faunal Species

India covers nearly 2.4% of the global geographical area and is a home to 8% of the faunal and floral species known globally. The Zoological and Botanical Survey of India has played a key role in discovery of new species and has reported the current estimates of faunal and floral species to be 1,00,693 and 48,655 respectively (NR6 2018). India's plant and animal species constitute around 11.2% of global floral and nearly 6.7% of the faunal species in the world. Furthermore, to its rich variety in species India takes pride in its escalating rates of endemism: 28.2% floral and 28.7% faunal endemic species. India has gathered immense traditional knowledge through continuous exploration of biological resources. As per the MOEFCC (Ministry of Environment Forest and Climate Change) globally, India ranks 10th in birds in the group of endemic vertebrate group, 5th in reptiles and 7th in amphibians.

3.2 Terrestrial Ecosystems

India ranks 10th in the world with 24.4% of its land area under forests (ISFR 2017) and ranks 8th globally in its net gain from forests (FAO and UNICEF 2017). Moreover most of the increase in the forest cover is in the category of very dense forests which absorb carbon dioxide, thereby increasing the carbon stock of the forests by 38 million tonnes as compared to previous years. India has been recognized among 12 mangrove-rich countries in the world possessing a mangrove cover of 4921 km^2 which accounts for 2% of the total global area under mangrove. India comprises of 16 forest types of which 38.2% are tropical dry deciduous forests and 30.3% are tropical moist deciduous forests. India's National Forest Policy focuses on reforestation of deteriorated forests, promotion of conservation reserves to be monitored by the community outside the protected areas, enhancement of the economy services of the ecosystem, combating climate change and creating awareness among the stakeholders at all levels (FLR). Forest landscape restoration aims to restore functional ecological systems and enhancing the quality of life across deforested landscapes. The prime focus of the FLR is to meet India's commitment to Bonn Challenge Pledge. India has also initiated the Restoration Opportunities Assessment Methodology (ROAM) which has been developed by IUCN in collaboration with World Resources Institute (WRI), in the Himalayan state, Uttarakhand. The Wildlife (Protection) Act, 1972, has promoted afforestation and the number of protected areas (PAs) have increased from 690 to 770 and the geographical area covered under these protected areas has also increased from 16,685 to 1,62,098.57 km^2 from the period of 2014 to 2017 (NR6 2018) making 4.9% of India's geographical area to fall under the category of protected areas (PAs) which include wildlife sanctuaries (544), national parks (104), conservation reserves (77) and community reserves (46) respectively. The wildlife protected areas promote conservation of threatened faunal species: tiger reserves (39) and elephant reserves (28) respectively. Six of India's national parks are among the world heritage sites namely Kaziranga, Manas, Keoladeo, Sundarbans, Nandadevi (including valley of flowers) and the Western Ghats serial site which undergo constant monitoring under several projects like 'Enhancing Our Heritage' being run by UNESCO in collaboration with IUCN. Further, in cooperation with neighbouring nations India has classified 12 Transboundary protected areas in its continued efforts towards biodiversity conservation. Moreover, India is getting closer to achieve its national goal of making 33% of its area under tree cover as there has been an increase in the area covered by Trees Outside Forests (TOF) by 1243 km^2 since 2015. Further to its success in the various initiatives taken up in forestry, India has set up a forests mapping programme for forests and tree cover taken up by the Forest Survey of India.

3.3 Aquatic Ecosystems

India possesses a variety in its wetland ecosystems which ranges from cold arid zone wetlands to hot and wetlands of the coastal region. Around 4.7% of India's geographical land is covered by freshwater ecosystems which are home to 9456 species making up for 9.46% of the total number of diverse animal species of India (Bassi et al. 2014). Moreover, as per the Wetland (Conservation and Management) Rules, 2017 the individual states are responsible for the conservation of wetlands beyond the boundary of protected areas (PAs). Therefore, there has been a constitution of 'State Wetland Authority' by many states in India. The NPCA (National Plan for Conservation of Aquatic Ecosystem) and the NWCP (National Wetland Conservation Program) has 65 lakes and 115 wetlands under its cover of integrated management of which 25 wetlands have already been identified as Ramsar sites. Further, between the period of 2015–17 seven Ramsar sites management plans were upscaled to integrated management plans (NR6 2018). The Indian marine and coastal ecosystems possess a long coastline which stretches around 7517 km^2 (Nayak 2017) hosting around 20,444 faunal species of which 1180 are in the Red List (IUCN) of threatened species. Moreover, these ecosystems encompass 2.02 million km of EEZ (exclusive economic zone) and a varied range of ecosystems including lagoons, estuaries, backwaters, mangroves, rocky coasts, salt marshes, and coral reefs which are biodiversity rich components. The last two decades have witnessed a shift in the trend from fisheries to aquaculture. India ranks second in the production of fish and aquaculture globally with nearly 2500 species of fish. Moreover, a distribution of nearly 800 freshwater fish species including more than 200 endemic fishes were recorded in the Blue Revolution or *Neel Kranti Mission*, 2016–2020. The Wildlife Institute of India (WII) has nominated additional 106 sites for prioritized conservation under the category of Important Coastal and Marine Areas (ICMBAs) of which 22 ICMBAs are listed under the category of Communities Reserve for immediate conservation.

3.4 Agricultural and Genetic Biodiversity

India is recognized globally as one among the eight Vavilov centres of origin being the centre of origin for rice. It is well known for its agrobiodiversity with fifteen varied agroclimatic zones wherein differential and dynamic practices of farming are being carried out in line with the regional climate, soil and topographic features. India has contributed immensely to crop biodiversity with more than 50,000 varieties of rice, followed by 5000 varieties of sorghum and 1000 varieties of mangoes (ICAR 2018). India has several success stories in agrobiodiversity being the centre of origin of rice and standing first globally in production of millets, fourth in the world production of crops such as pearl millet, sorghum, finger millet and maize. The NBPGR (National Bureau of Plant Genetic Resources), NBAGR (National Bureau of Animal Genetic Resources), NBFGR (National Bureau of Fish Genetic Resources), NBAIR (National Bureau of Agricultural Insect Resources), and NBAIM (National Bureau of Agriculturally Important Microorganisms) under the cover of ICAR (Indian Council of Agricultural Research) are responsible for conserving the genetic diversity of India. During the period of 2014–2018, registration, and preservation of several species of animals, fish, insects, agriculturally important microorganisms including 4,37,000 accessions of plant germplasm was carried out by the National Gene Bank respectively. The NBAGR has been successful in registration of 169 native breeds of poultry and livestock by the middle of the year 2018. Identification of 22 agrobiodiversity hotspots has been done by PPVFRA (Protection of Plant Varieties and Farmers' Rights Authority) and the efforts of farmers and their communities in plant genetic resources conservation has been recognized as 'Plant Genome Saviour Community Award' and the 'Plant Genome Saviour Farmer Reward' respectively. In India, nearly 8000 medicinal plants are being utilised owing to their therapeutic properties. However, in situ conservation in collaboration with ex situ cultivation (Natarajan et al. 2018) has brought about a decline in the sourcing of plants with medicinal properties from the wild as around 110 medicinal plant conservation areas (MPCAs) have been constituted in the forests in protected areas, while the ex situ cultivation outside the forests aids in meeting the demand of around 40% of the medicinal plants.

4 Effective Management of Factors Affecting India's Biodiversity Loss

India as a nation experiences several threats which interfere with its continued efforts towards conservation of biodiversity, which primarily includes effect of human activity, loss of habitat, shrivelling genetic diversification, resource exploitation, competitive alien species, desertification and climate change, pollution and diminishing forest cover. India faces a constant challenge of balancing the livelihood needs of an escalating population and upscaled conservation of biodiversity.

4.1 Hotspots

Among the 35 biodiversity hotspots in the world 4 are present in India namely, Western Ghats in India being the part of Western Ghats-Sri Lanka global hotspot, Nicobar Islands being the part of the Sundaland hotspot, North-eastern region of India which includes parts of Assam and Meghalaya as part of Indo-Burma hotspot, and the Eastern Himalayas encompassing the North-eastern Himalayas of India, Nepal and Bhutan. The Eastern Himalayas, and the Western Ghats comprise the mountain ecosystem of India. They are rich in their geographical, sociological, cultural and bio-physical heritage and diversity. These ecosystems have a high percentage of endemism as in vascular plants alone endemic species range between 32 and 40%. Further, in Western Ghats more than 50% endemic species have been observed for reptiles, fish and amphibians. More than 950 species of birds have been identified in the Himalayan region. The Economics of Ecosystems and Biodiversity, The India Initiative (TEEB-TII), (MOEFCC 2015) has been working towards involvement of local communities in computation of ecosystem services in the Western Ghats. The conservation, and rehabilitation of the Himalayan hotspot is promoted by the National Mission for Sustaining the Himalayan Ecosystems.

4.2 Extinction of Species

Efforts have been made in restoration of threatened species through varied strategies and recovery programmes which includes reintroducing the endangered species into their natural habitat with restrictions on trade and exhibition. Furthermore, India, as a CITES (Convention on International Trade in Endangered Species) Party, plays an active role in the prohibition of international trade of threatened wild species and various policies and initiatives have been employed in management of menace from encroaching alien species. The threatened plant species which includes pitcher plants, mangroves, orchids, endemic tree species, gymnosperms, RET plants, bulbous plants, ferns and medicinal plants have been restored. An initiative by the DBT (Department of Biotechnology) has been on prevention of extinction and conservation of plants falling under the threatened category by optimising the tools from biotechnology. Also, organizations like (MFF) Mangroves For the Future (IUCN) aims to protect the coast lines and marine ecosystems. In addition, the IDWH (Integrated Development of Wildlife Habitat) and MIKE (Monitoring the Illegal Killing of Elephants) has been working successfully on protection and monitoring of tigers and elephants along with 17 other faunal species which includes Great Indian bustard, Asian wild buffalo, dugong, Asiatic lion, brow-antlered deer, white nest swiftlet, hangul, Gangetic river dolphin, Indian rhino, Jerdon's courser, marine turtles, Malabar civet, ibex, snow leopard, Nicobar megapode, vulture and swamp deer. The current trends reveal an increase in the population of these species along with the

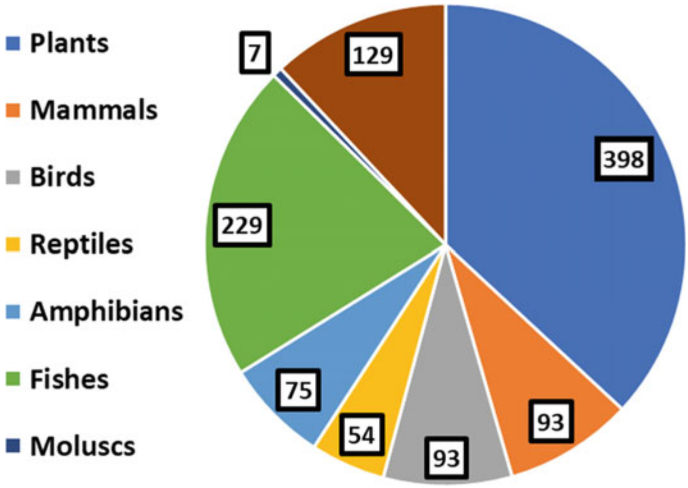

Fig. 1 Threatened species in INDIA: IUCN Red List categories (IUCN 2019-1)

number of tigers increasing from 1827(1972) to 2226(2014) and the number of elephants increasing from 1200(1970) to 27,000(2015). In its efforts to protect the birds, 554 IBA (Important Bird Areas) have been recognized. The Government of India has also signed the Regional Declaration for the conservation of endangered Gyps species as a part of the South Asia Vulture Initiative. IUCN (International Union for Conservation of Nature) Red List, 2019 categorises species of plants, animals and other organisms threatened with the possibility of extinction into groups like critically endangered, endangered and vulnerable species. It measures the conservation status of species and thereby the impact of human activities on the health of ecosystems. Figure 1 represents the total threatened species of India (1078) of which the most threatened are plant species, followed by fishes and invertebrates. Figures 2 and 3 depicts India's fauna and flora in the IUCN Red List categories and majority of the plants and animals are falling under the category of least concern. However, the critically endangered animal and plant species as per the IUCN red list are 81 and 76 respectively.

4.3 Climate Change

In the present scenario of global change in climatic conditions, biodiversity of ecosystems is facing a major blow ranging from melting glaciers to desertification of land. India has evolved several strategies to fight against fluctuations in climate by adopting a National Plan on Climate Change (NAPCC), focussing on eight prominent areas which affect biodiversity conservation namely urban habitat, forest, solar energy, energy and water use efficiency, knowledge on biodiversity, Himalayan ecosystem

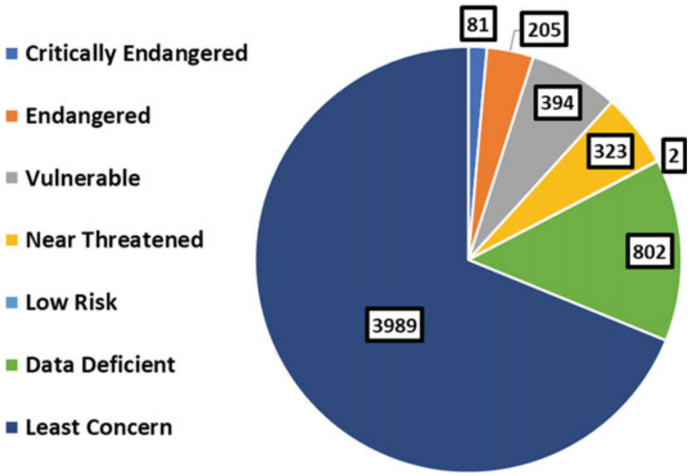

Fig. 2 India's faunal species in IUCN Red List categories (IUCN 2019-1)

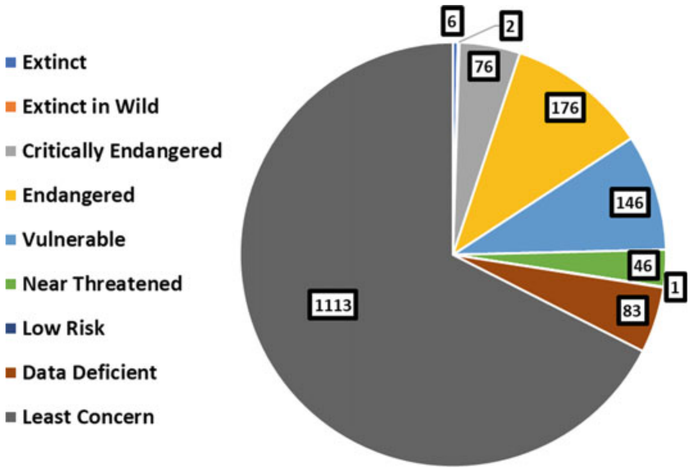

Fig. 3 India's floral species in IUCN Red List categories (IUCN 2019-1)

and agriculture. With the adoption of REDD + (Reducing Emissions from Deforestation and Forest Degradation) initiative in 2018, India has made a strong move to tackle climate change. Further in the agricultural sector, owing to the current global climatic changes, robust varieties of crops which can flourish in varying climatic conditions have been introduced in more than 150 villages in India under NICRA (National Innovations in Climate Resilient Agriculture). The IUCN's Coping with Uncertainties Initiative is an attempt to equip people living in the three Himalayan States Uttarakhand, Himachal Pradesh and Sikkim with climate resilient interventions.

4.4 Pollution

All types of pollution whether air, water or land act as hazards towards conservation of biodiversity. Central, state and regional boards a have been involved in programme implementation of missions like *Namami Gange.* The initiatives taken up by the water quality monitoring programme has brought about positive changes across the country-Chilika Lake (Odisha), Loktak lake (Manipur), Mangroves (Sunderbans) and Aravali Park (Delhi) to name a few. The use of pesticides for agriculture has been under supervision to reduce their intake as well as promote the soil quality. Under NMSA (National Mission for Sustainable Agriculture) there has been an escalated usage of biofertilizers as compared to the chemical fertilizers. Moreover, the practise of organic farming has witnessed an escalating trend from 1.2 million hectares in 2014 to 1.46 million hectares in 2016 respectively. In addition, the *Swachh Bharat Abhiyan* and the green highways policy has strengthened India's efforts to curb pollution and promote biodiversity conservation. The industrial superpowers in India like Tata Steel, Tata Power, Aditya Birla Group have a Biodiversity Policy in partnership with IUCN Leaders for Nature (LFN) as an encouraging platform for companies in the private sector to perform their business operations woven around concerns of biodiversity.

4.5 Dwindling Traditional Knowledge

India's traditional knowledge is an asset to its biodiversity conservation and plays a vital role in bioprospecting. The ministry of AYUSH (Ayurveda, Yoga & Naturopathy, Unani, Siddha & Homoeopathy) has developed a digital library on traditional knowledge (TKDL) with nearly 3 lakh pharmaceuticals using natural raw material. Furthermore, at the local level several organizations are working under the ministry of MOEFCC to promote documentation of the valuable traditional knowledge for future generations.

4.6 Alien Invasive Species

A total of 169 alien species have been reported in varied ecosystems of India as represented in Fig. 4. Effective strategies like allowance of growth of competitive indigenous species and native grasses which can rule out the alien species, and planning by teams of biologists, researchers, hydrologists and other experts in the field have helped in management of these species and restoration of ecosystems. TFRI (Tropical Forest Research Institute) has been working extensively in eradication of invasive species like *Lantana camara.* Moreover, prevention of plants and pests

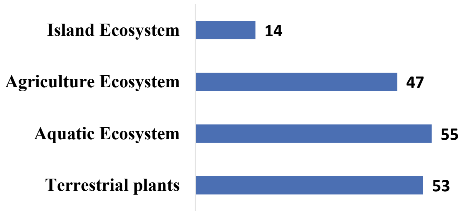

Fig. 4 Number of invasive alien species reported in ecosystems of India (NR6 2018)

which could cause destruction to indigenous species is kept in check by measures like isolation and phytosanitation (Kanaujia et al. 2018).

5 Biodiversity Conservation: India's Legislative, Administrative and National Policies

As a nation India has been battling these threats with effective designing of national policies, administrative and legal measures for conservation of biodiversity. Moreover, these measures are implemented towards bringing about a shift in the ever-growing demands from natural habitat and ecosystems to alternative sources and promote biodiversity conservation. In pursuit of CBD, India framed the National Policy and the Macro Level Action Strategy on Biodiversity (1999) (Singh et al. 2018). Furthermore, to emphasize on the micro level action plans India implemented the National Biodiversity Strategies and Action Plan (2000–2004). There are several programmes running under this plan which focus on Protected Areas (PAs) network, strengthening of biosphere reserves, creation of more species specific reserves, expansion in labelled Ramsar sites, enhancement of the ex situ attempt by creating a chain of Lead Gardens and several promising initiatives to conserve our genetic resource. Following the approval of India's National Environment Policy (2006) focussed efforts were directed towards consolidation of the National Biodiversity Action Plan (2008). India enacted the Biological Diversity Act (2002) as one of the key progressive legislation in favour of conservation of biodiversity in the country by strengthening the effectiveness of the objectives of CBD. The implementation of this act has been carried out at the National level (National Biodiversity Authority), State level (State Biodiversity Boards) and local level (Biodiversity Management Committees).

The United Nations has defined the tenure of UN Decade on Biodiversity (UNDB) from 2011–2020 which aims to achieve the global plan for biodiversity (2011–2020) along with its Aichi biodiversity targets focusing on a unique approach to integrate biodiversity with social and economic factors at the crux of the problem and thus provide promising solutions. The Convention on Biological Diversity has played the prime role in implementation of UNDB mission by initiating the involvement of governments of the member countries in laying out their National Biodiversity Action Plan and gel it into wider national plans for biodiversity conservation.

In pursuit of CBD, India consolidated 12 National Biodiversity Targets in accordance with Aichi targets to meet its desired goal of biodiversity conservation by 2020. Table 1 describes the targets along with effective policies and legislative procedures involved in accomplishment of each target.

Some of the landmark laws and policies in biodiversity conservation include the following:

- Biodiversity Act (2002–2004)
- National Environmental Policy (2006)
- National Biodiversity Action Plan (2008)
- National Wildlife Action Plan (2002–2016), (2017–2030)
- National Forest Policy (1988, Draft 2018)
- National Afforestation Plan for Climate Change (2008)
- Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006
- Wildlife Crime Control Bureau (2008)
- Green India Mission (2014)
- Mahatma Gandhi National Rural Employment Guarantee Act (2005)
- National Fisheries Development Board (2006)
- Wetlands (Conservation and Management) Rules, 2017
- National Policy on Marine Fisheries (2017)
- Blue Revolution (2015–2020)
- National Policy for Farmers (2007)
- Protection of Plant Varieties and Farmers' Rights (PPV & FR) Act (2001)
- International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (2004)
- National Biotechnology Development Strategy (2015–2020).

Moreover, India's National Biodiversity Targets are in sync with the global objectives of biodiversity conservation which include international frameworks:

- United Nations Framework Convention on Climate Change
- United Nations Convention to Combat Desertification
- United Nations Forum on Forests
- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)
- Convention on the Conservation of Migratory Species of Wild Animals
- International Treaty on Plant Genetic Resources for Food and Agriculture
- World Heritage Convention (WHC)
- Convention on Wetlands (Ramsar Convention)
- International Plant Protection Convention (IPPC)
- International Treaty on Plant Genetic Resources for Food & Agriculture (ITPGFRA)

Table 1 Initiatives taken by India to achieve National Biodiversity Targets

National biodiversity target	Measures taken: policies and initiatives
1. By 2020, a significant proportion of the population especially the youth, is aware of the values of biodiversity and the steps they can take to conserve and use it sustainably	Communication, Education and Public Awareness (CEPA) Program, *Swachh Bharat Abhiyan,* Green Skill Development Programme, Secure Himalaya programme, Kailash Sacred Landscape initiative, Citizen Science initiative, and the Environmental Information System
2. By 2020, values of biodiversity are integrated in national and state planning processes, development programmes and poverty alleviation	*Pradhan Mantri Krishi Sinchayee Yojna* (PMKSY), *Har Khet Ko Paani*, Market Development of Tribal Products/Produce (TRIFED), Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Solar projects and Green energy corridor projects
3. Strategies for reducing rate of degradation, fragmentation and loss of all-natural habitats are finalized and actions put in place by 2020 for environmental amelioration and human well-being	**Forest Habitat**: Green India Mission, *Pradhan Mantri Ujjwala Yojana* (PMUY) **Aquatic Habitat**: *Namami Gange*—Ganga Conservation Mission, National Water Quality Monitoring Programme, National Plan for Conservation of Aquatic Ecosystems, National River Conservation Plan, Aquifer Management Programme, *Jal Kranti Abhiyaan,* Integrated Wasteland Development Project, Integrated Coastal and Marine Area Management, Integrated Coastal Zone Management Programme **Terrestrial Habitat**: Desertification and Land Degradation Atlas of India (2016), National Carbon Project
4. By 2020, invasive alien species and pathways are identified and strategies to manage them developed so that populations of prioritized invasive alien species are managed	National assessment of Tigers, Plant Quarantine (Regulation of Import into India) Order, 2003, Destructive Insects and Pests Act, 1914, National Forest Policy 1988 amended 2018, Livestock Importation Act, 1898

(continued)

Table 1 (continued)

National biodiversity target	Measures taken: policies and initiatives
5. By 2020, measures are adopted for Sustainable Management of Agriculture, Forestry and Fisheries	**Sustainable Management of Agriculture**: Indian Council for Agricultural Research (ICAR), National Innovations on Climate Resilient Agriculture (NICRA), National Mission to Ensure Sustainable Agriculture (NMSA) 2014, National Mission on Oil seeds and Oil Palms 2014, National Mission of Agricultural Extension and Technology 2014, Mission for Integrated Development of Horticulture 2014, *Paramparagat Krishi Vikas Yojana* (PKMY) 2015, Mission Organic Value Chain Development for North Eastern Region, 2014–15, *Pradhan Mantri Krishi Sinchai Yojana*, 2015—"Per Drop More Crop, *Kisan Urja Suraksha evam Utthan Mahabhiyan* (KUSUM)" **Sustainable Forestry**: Forest Survey of India, Forestry Education and Research (ICFRE), Wildlife Institute of India, National Farmers Policy, 2007, Plant Quarantine (Regulation of Import into India) Order, 2003, National Agroforestry Policy, 2002, Protection of Plant Varieties and Farmers' Rights National Wildlife Action Plan 2017–2030, Wildlife Crime Control Bureau, The Water (Prevention and Control of Pollution) Act, 1974, Coastal Regulation Zone Notification, 1991, 2011, Hazardous wastes (Managing and Handling) Rules, 1989 **Sustainable Fisheries**: Network for Fish Quality Management and Sustainable Fishing (NETFISH) 2007, Policy guidance on light fishing

(continued)

Table 1 (continued)

National biodiversity target	Measures taken: policies and initiatives
6. Ecologically representative areas on land and in inland waters, as well as coastal and marine zones, especially those of particular importance for species, biodiversity and ecosystem services, are conserved effectively and equitably, on the basis of protected area designation and management and other area-based conservation measures and are integrated into the wider landscapes and seascapes, covering over 20% of the geographic area of the country, by 2020	Wetlands (Conservation and Management) Rules, 2017, National Marine Fisheries Policy, 2017, Water (Prevention and Control of Pollution) Act, 1974 amended in 2003, Noise Pollution (Regulation & Control), 2000, The Air (Prevention and Control of Pollution) Act enacted in 1981 and amended in 1987, Environment (Protection) Act, 1986, Forest Conservation Act, 1980, Wildlife (Protection) Act, 1972, Indian Forest Act, 1927, Protection of Plant Varieties and Farmers' Rights Act, 2001, National Afforestation Plan, India's National Action Plan for Conservation of Migratory Birds, Sacred Groves, National Plan of Action for the Conservation and Management of Sharks, National Air Quality Monitoring Programme, National Ambient Noise Monitoring Network
7. By 2020, genetic diversity of cultivated plants, farm livestock, and their wild relatives including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity	Indian Council of agricultural Research, National Bureau of Agricultural Insect Resources, National Bureau of Agriculturally Important Micro-Organisms, National Bureau of Animal Genetic Resources, National Bureau of Fish Genetic Resources, National Bureau of Plant Genetic Resources, My Village My Pride (*Mera Gaon Mera Gaurav*), *Rashtriya Gokul Mission*, *2014*, Ministry of AYUSH

(continued)

Table 1 (continued)

National biodiversity target	Measures taken: policies and initiatives
8.By 2020, ecosystem services especially those relating to water, human health, livelihoods and well-being, are enumerated and measures to safeguard them are identified taking into account the needs of women and local communities particularly the poor and vulnerable	**Major Livelihoods Programs**: Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Deendayal Antyodaya Yojana—National Rural Livelihoods Mission **Urban Green Spaces**: *Nagar Van Udyan Yojana*, Smart City Initiative **Promotion of Green Energy**: National Solar Mission, *Deendayal Upadhyaya Gram Jyoti Yojana*, SAUBHAGYA—*Pradhan Mantri Sahaj Bijli Har Ghar Yojana* to achieve universal household electrification by March 2019, Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Energy Conservation Act 2001 **Road Connectivity**: *Pradhan Mantri Gram Sadak Yojana* **Education**: The Right of Children to Free and Compulsory Education Act, 2009, National Policy on Education 1986 **Health Services**: **National Health Mission (NHM)** National Rural Health Mission (NRHM), National Urban Health Mission (NUHM), National Disease Control Programmes, National Tobacco Control Programme (NTCP), National Programme for Health Care of Elderly and National Programme for Prevention and Control of Fluorosis, National Iodine Deficiency Control Programme, Mid-Day Meal Programme, ICDS, *Pradhan Mantri Swasthya Suraksha Yojana* (PMSSY) **Special Focus on Women**: *Janani Shishu Suraksha Karyakaram* (JSSK), *Rashtriya Kishor Swasthya Karyakram, Rashtriya Bal Swasthya Karyakram* **Drinking Water**: National Rural Drinking Water Programme
9. By 2015, access to Genetic Resources (GRs) and the Fair and Equitable Sharing of Benefits Arising from their Utilization as per the Nagoya Protocol are operational, consistent with national legislation	Guidelines on Access to Biological Resources and Associated Knowledge and Benefit Sharing Regulations, (Guidelines 2014), Biological Diversity Act, 2002 and Biological Diversity Rules, 2004, Protection of Plant Variety and Farmers' Rights Act, 2001, The Patents Act, 1970

(continued)

Table 1 (continued)

National biodiversity target	Measures taken: policies and initiatives
10. By 2020, an effective participatory and updated national biodiversity plan is made operational at different levels of governance	National Policy on Marine Fisheries, 2017, Green Highways Policy, 2015, National Biotechnology Development Strategy, 2015–2020, Fertilizer Control Order, 1985, National Solar Mission, Biodiversity and Business Initiative, National Plan for Conservation of Aquatic Ecosystem (NPCA) Mission, *Jal Kranti Abhiyaan*, National Water Quality Monitoring Programme, Development of Desertification and Land Degradation Atlas of India 2016
11. By 2020, national initiatives using communities' traditional knowledge relating to biodiversity are strengthened, with the view to protecting this knowledge in accordance with national legislations and international obligations	Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006, Geographical Indication of Goods (Registration and protection) Act, 1999, National Intellectual Policy Rights Policy, 2016, Traditional Knowledge Digital Library (TKDL), National Innovation Foundation, 2010, National AYUSH mission (2015–16), National Medicinal Plants Board
12. By 2020, opportunities to increase the availability of financial, human and technical resources to facilitate effective implementation of the Strategic Plan for Biodiversity 2011–2020 and the national targets are identified and the Strategy for Resource Mobilization is adopted	Biological Diversity Act, 2002, National Environment Policy, 2006, Implementation of Biodiversity Finance Initiative (BIOFIN), National Biodiversity Action Plan, 2008 and its Addendum, 2014

Sixth National Report (NR6) to the Convention of Biological Diversity, MOEFCC (2018)

6 Case Studies

6.1 Case Study 1: Promoting Biodiversity in Neighbourhood Parks in an Urban Landscape (Swamy et al. 2019)

The present study focuses on biodiversity conservation in the developing city of Bangalore in the southern part of India, which was once referred as the "garden city" of India encompassing several gardens and highly stratified local species of plant has now been transformed into a "silicon city" with changes in landscape characteristics, loss of gardens and consisting of exotic plant species in the recent times. It emphasizes on the role of small green patches in urban areas, which are neglected as compared to the large green spaces. The cities in India have been observed to have plenty of pocket green spaces in terms of neighbourhood parks (NPs) in residential areas which are meant for recreational activity being neglected for the role they can play in biodiversity conservation. To estimate the biodiversity status within 37 neighbourhood parks in Bangalore; "biodiversity fondness survey" was carried out by administering a questionnaire to the citizens and their biodiversity preferences were found to be butterflies and birds, as compared to other taxa like insects. These preferences could be rooted with traditional practices and believes. Further on, making use of peoples' preferred species as Umbrella species positive changes could be brought about in traditional gardening practices which could also benefit many other taxa. Moreover, management of butterflies and birds encompass a wide range of habitats suitable for other not known taxa. This study has also revealed that birds are good surrogates for insects.

Also, the landscape characteristics around the neighbourhood parks were analyzed and identified to enhance the biodiversity within these parks. The results revealed 55 species of trees, 45 bird species, 41 butterfly species and 68 morpho species of insects. Moreover, the habitat determinants within these parks could play a vital role in richness of the native species. The large neighborhood parks depicted an elevated presence of birds (more canopy cover), insects (higher proportion of lawns) and butterflies (higher proportion of shrubs) as compared to small NPs. The study focussed on the density of the small green patches rather than its size as an important criterion to support biodiversity. The study observed higher butterfly diversity in small NPs with high density indicating that along with heterogeneity and the habitat composition within the NPs, the social and cultural environment of the neighbourhood plays a key role in determination of the biodiversity at the local level. Though the birds are predominantly dependent on large green spaces, the migrant birds like *Phylloscopus trochiloides* and *Acrocephalus dumetorum* were observed in the wild vegetation surrounding the neighbourhood parks. The lined-up trees in the neighbourhood act as corridors for these birds and allow them to extend their habitat requirements. An equal proportion of exotic and native trees was observed within neighbourhood areas. The recent studies have found the exotic species worthy and not a threat to a habitat as they support the native species specially in an urban landscape. The study observed that the landscape configuration in Bangalore city was either single large or several small in terms of size. Moreover, high density neighbourhood parks without the support of a large green space and low-density neighbourhood parks along with the influence of large green spaces could promote rich diversity of butterflies and birds. Further, several small green patches could represent a single large space, which are currently dwindling in current times due to development and industrialization. Projects like "Citizen Science" and "Backyard Wildlife" have begun to emerge in India and are working towards creating green neighbourhoods with effective community participation and promoting biodiversity conservation.

6.2 Case Study 2: Conservation of Medicinal Plants (Negi et al. 2018)

The medicinal and aromatic plants have been explored from time immemorial for their healing properties along with minimal side effects as compared to other chemical drugs. The Indian Himalayan Region is one the major sites where these plants are found in abundance and lure the health care sector with the increasing inclination towards use of natural biomolecules. The MAPs also play a vital role in boosting India's economy as evidence indicates most of the medicinal plants being used globally for health care are obtained from developing countries and the global market has observed a growth rate of 6.6% from 2015 to 2020. The decline in the diversity of medicinal and aromatic plants along with their traditional knowledge would grossly effect the human well-being and livelihood in the near future. Therefore, conservation of these plants in the Himalayan biodiversity hotspot region is given utmost importance and priority as this region comprises of 8000 species of vascular plants and 1720 medicinal and aromatic plant species. Despite government policies towards protection of MAPs their numbers are declining and requires immediate attention. The present study highlights the role of four vital parameters: economic, governance, environmental and socio-cultural, with emphasis on 11 criteria along with 48 indicators for assessment of the sustainability of medicinal and aromatic plants. It was observed that the registration of farmers for cultivated fields of MAPs, awareness regarding high demand of medicinal plants and prioritised MAPs among cultivators and farmers, simplified cultivation and marketing scenarios, safeguarding traditional knowledge on MAPs and protection of MPCAs (Medicinal Plant Conservation Areas) could prove to be effective as policy inputs. The study identified 152 medicinal plant species (herbs, trees and shrubs) in western Himalayas of which 43 were given priority for conservation in Western Himalayas as they fall under the category of Globally Significant Medicinal Plants (GSMPs) and could be collected from cultivated fields of registered farmers and not from the wild. Most medicinal plants in the Indian Himalayan region were found in Meghalaya (850) followed by Uttarakhand (701) and Himachal Pradesh (643). Moreover, of the known medicinal plants in the region 62 species were endemic along with 208 species with near endemic status. Further, the various organizations working in the MAPs sector were identified under the ministry of AYUSH and GBPNIHESD was noted for its research and development activities evolving in vitro techniques for several MAPs and creating awareness of high value MAPs in the Indian Himalayan region.

7 Conclusion

India has a legacy of rich and varied socio-cultural heritage and biodiversity. India has been recognized as a Megadiverse country owing to its biological wealth which encompasses a huge variety of floral and faunal species and diverse ecosystems. India has achieved several recognitions for its initiatives in the field of biodiversity enhancement. However, the country's biodiversity faces several threats which needs to be addressed to protect and conserve its diverse strength of species and ecosystems. Effective planning, policy making, execution and monitoring along with international support has equipped India well in the management of the deleterious impact on biodiversity due to human activity. India is functioning, in tune, with the global concern on conservation of biodiversity and has established several laws and policies to strengthen its commitment towards United Nations action plan for biodiversity conservation.

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Impact of Weather Shock on Food Insecurity: A Study on India

Raju Mandal and Munmi Sarma

Abstract This chapter makes a novel attempt to examine food insecurity in India and its variations across space and different social and religious groups. It further intends to examine the impact of weather shock on food insecurity in India and also identify the socio-economic factors that affect the same. The results of analysis based on the second round of India Human Development Survey, 2011–12 reveals large variations in the extent of household level food insecurity across India and also its various socio-religious groups. The binary logistic regression results show that weather shocks have a positive impact on the probability of a household to be food insecure. Moreover, size of households, dependency ratio, poverty and urban residence make a household more likely to be food insecure. On the other hand, per capita income, female adult education, remittances and cultivation as the main occupation reduce the probability of food insecurity.

Keywords Weather shock · Food insecurity · India

1 Introduction

Despite unsettled controversies about the extent and causes of changes in climatic conditions there is now unanimity regarding the fact that the global climate has changed noticeably during the last one century. According to a special report by IPCC, the anthropogenic global warming reached approximately 1 °C higher than the pre-industrial level in 2017, the increase being at the rate of 0.2 °C per decade (Allen et al. 2018). The ongoing climate change that is expected to go from bad to worse in the coming decades has the potential to affect different sectors of an economy. Agricultural sector which is critically dependent on the climatic factors like temperature and rainfall would be worst hit, especially in the developing countries.

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Developing countries, many of which have average temperatures that are already near or above crop tolerance levels, are predicted to suffer an average 10–25% decline in agricultural productivity by 2080s (Mahato 2014). Climate change would affect not only agricultural production but also food security and the effects are likely to be higher in the developing countries.

One of the major challenges faced by the countries today is to achieve and maintain food security for its growing population. This has been made more challenging because of the fact that food security requires not only availability of a sufficient physical quantity of food but it has to be accessible to people, nutritious in contents and stable over time. Technological improvements on the one hand and trade liberalization on the other have enabled a country like India to increase availability of physical quantity of food. Nonetheless, it has not been accessible to millions of households which is quite evident from the fact that more than a third of its population is estimated to be absolutely poor, and as many as half of its children have suffered from malnourishment over the last three decades (Upadhyay and Palanivel 2011). According to Radhakrishna (2005), the achievement of macro foodgrain security at the national level did not percolate down to households as a result of which the level of chronic food insecurity in India is still high. On the other hand, use of excessive chemicals in cultivation and adulteration of food items have severely spoiled their nutritional contents. In the process of intensive use of both natural and chemical factors for producing rice and wheat the Green Revolution has led to serious environmental problems such as reduction in soil fertility, imbalance in nutrient contents of soil, depletion of groundwater etc. (Bhushan 2018), which has the potential to adversely affect not only production but also their nutritional quality.

The challenge of food and nutrition security has been exacerbated due to global climate change in a country like India where majority of the population depends on agriculture for their life and livelihoods and who, being poor, have the limited capacity to adapt to the adverse effects (Mandal and Nath 2018). Food security and all its four dimensions, viz., availability, accessibility, utilization and stability will be adversely affected by climate change (Krishnamurthy et al. 2012). Availability of sufficient food is expected to decline due to reduced productivity induced by rising temperature, extreme weather events, pests and diseases of crops (Noiret 2016). Second, access to food will be impacted by the increase in food prices resulting from reduced yield, decline in rural income and increase in poverty—all induced by climate change (Noiret 2016; Hallegatte et al. 2016; Morton 2007). Wheeler and Von Braun (2013) find that the impact of climate change on food security is worst in countries already suffering from hunger. Third, climate change can increase the incidence of various types of diseases (Cauchi et al. 2019; Confalonieri et al. 2007; IPCC 2007) thereby adversely affecting the ability of individuals to absorb and utilize nutritional contents of food effectively (Schmidhuber and Tubiello 2008). Finally, stability of food supply is also going to be affected due to expected increase in the intensity and frequency of extreme weather events (Krishnamurthy et al. 2012).

The objective of this chapter is to examine and quantify the extent of food insecurity in India and its variations across states and union territories, and various social and religious groups. It further intends to examine the impact of weather shock on food insecurity in India and also identify the socio-economic factors that affect household level food insecurity. It adopts a novel approach to measure household level food insecurity by taking into account nutritional requirement of an individual on the basis of recommendation of the Indian Council of Medical Research (Government of India 2014). The available literature in this regard has mainly focused on food security in India (Dev and Sharma 2010; Kumar et al. 2012; Brahmanand et al. 2013; Ittyerah 2013; Singh 2014), and a few others have studied food insecurity on a regional basis (Agarwal et al. 2009; Chinnakali et al. 2014; Mukherjee 2016). But till date, no study has been carried out for examining the impact of weather shock on household level food insecurity in India.

This chapter has important environmental and socio-economic dimensions. As discussed earlier food security is dependent on food production, among others, which in turn is critically dependent on environmental factors like temperature and rainfall. Most of the Indian farmers being poor are reliant on rain-fed agriculture. Weather shocks—either in the form of excessive or deficient rainfall—may adversely affect agricultural production which may make people more vulnerable to food insecurity. Therefore, the main focus of this chapter is to examine the impact of weather shocks on food insecurity of Indian households. Moreover, food insecurity is also associated with socio-economic factors like income, occupation, social group, religion etc. Hence, this chapter also seeks to examine how these factors affect household level food insecurity.

This chapter is organized in six sections. Section two outlines the materials and methods. Section three discusses the extent of food insecurity in India and its variations across various social and religious groups. Section four outlines the model with a brief explanation of the variables of interest. Section five discusses the regression results whereas section six deals with concluding remarks.

2 Materials and Methods

This study is completely based on secondary data collected from the second round of India Human Development Survey (IHDS-II) for the year 2011–12. The IHDS is a nationally representative survey conducted jointly by the University of Maryland and the National Council of Applied Economic Research. The IHDS-II covers a sample of 42,152 households spread across 33 states and union territories, 384 districts, 1420 villages and 1042 urban blocks. The geographical composition of the sample is shown in Appendix 1.

The IHDS provides data at the household level on a number of dimensions and variables. The data are thoroughly cleaned and a few variables relevant for the present study are taken into account while a few others are created from the data set. A detailed analysis of the variables used in the study is provided in Sect. 4.

The main objective of the chapter is concerned about household level food insecurity. Hence household level food insecurity is measured as follows. The report of the Expert Group (Rangarajan) to the Planning Commission (Government of India

2014) has outlined the normative requirements of expenditures on food comprising calories, proteins and fats.[1] We have taken this recommended expenditure (per capita per month) on calories, proteins and fats as the benchmark for measuring food insecurity. Thus, the national food insecurity lines, which takes due consideration of nutritional contents of food, have been defined as the monthly per capita food expenditure (calorie + protein + fat) of Rs. 554 in rural areas and Rs 656 in urban areas. These food insecurity lines are then adjusted by price indices to estimate state specific food insecurity lines (for details see Appendix-II). On the basis of these food insecurity lines an aggregate measure of food insecurity is obtained. The national and state specific food insecurity lines along with poverty lines are shown in Table 1. A household whose per capita monthly expenditure on calories, proteins and fats is less than this benchmark is considered to be food insecure.

3 Food Insecurity in India: Extent and Variations

The variations in the extent of food insecurity across different castes and religions are shown in Figs. 1 and 2 respectively. It is evident from these figures that there are wide variations in the prevalence of food insecurity across social and religious groups.

As far as the social groups are concerned, food insecurity is the highest among scheduled tribes (ST) with around 45% of their households being food insecure. In case of scheduled castes (SC) around 34% of the households are food insecure which is followed by other backward castes (OBC) (28.65%). Food insecurity is the lowest in case of general category people as percentage of insecure households belonging to this is only around 17%. Such differences in the extent of food insecurity are indicative of economic inequalities among these classes.

Figure 2 highlights the differences in the level of food insecurity across various religious groups in India. The point to be noted here is that for the convenience of our analysis we have grouped Buddhists, Jains, Tribals and other small religious groups (as reported in IHDS-II dataset) into one group and named it as 'Other Religion' due to the fact that each of its constituents represent a very small proportion of the sample households compared to other major religions. It is seen from Fig. 2 that around 45% households of this group are food insecure. Food insecurity is the lowest among the Sikhs (11%). It is interesting to note that there is not much variation across the other three major religions.

The extent of food insecurity and it spatial variations among the sample households are shown in Table 2. As seen from the table 27.68% of the sample households covering the entire India are food insecure. No sample household in Goa and Tripura are

[1]This Expert Group was constituted in June, 2012 by the Planning Commission under the Chairmanship of Dr. C. Rangarajan to suggest a methodology for measurement of poverty in India. It has re-computed the average requirements of calories, fats and proteins on the basis of the 2010 Indian Council of Medical Research norms (Government of India 2014).

Table 1 National and state specific lines for poverty and food insecurity

States/UTs	Poverty line		Food insecurity line	
	Rural	Urban	Rural	Urban
Andhra Pradesh	1031.74	1370.84	588.05	639.14
Arunachal Pradesh	1151.01	1482.94	656.03	691.41
Assam	1006.66	1420.12	573.75	662.12
Bihar	971.28	1229.3	553.59	573.15
Chhattisgarh	911.8	1229.72	519.69	573.34
Delhi	1492.46	1538.09	850.64	717.12
Goa	1200.6	1470.07	684.29	685.41
Gujarat	1102.83	1507.06	628.57	702.65
Haryana	1127.82	1528.31	642.81	712.56
Himachal Pradesh	1066.6	1411.59	607.92	658.14
Jammu & Kashmir	1044.48	1403.25	595.31	654.25
Jharkhand	904.02	1272.06	515.25	593.09
Karnataka	975.43	1373.28	555.95	640.28
Kerala	1054.03	1353.68	600.75	631.14
Madhya Pradesh	941.7	1340.28	536.73	624.89
Maharashtra	1078.34	1560.38	614.61	727.51
Manipur	1185.19	1561.77	675.51	728.16
Meghalaya	1110.67	1524.37	633.04	710.72
Mizoram	1231.03	1703.93	701.64	794.44
Nagaland	1229.83	1615.78	700.95	753.34
Orissa	876.42	1205.37	499.52	561.99
Punjab	1127.48	1479.27	642.62	689.70
Rajasthan	1035.97	1406.15	590.46	655.60
Sikkim	1126.25	1542.67	641.92	719.25
Tamil Nadu	1081.94	1380.36	616.66	643.58
Tripura	935.52	1376.55	533.21	641.80
Uttar Pradesh	889.82	1329.55	507.16	619.89
Uttarakhand	1014.95	1408.12	578.48	656.52
West Bengal	934.1	1372.68	532.40	640.00
Puducherry	1130.1	1382.31	644.11	644.49
Andaman & Nicobar Islands	1314.98	1797.69	749.48	838.16
Chandigarh	1303.17	1481.21	742.75	690.60
Dadra & Nagar Haveli	1008.39	1540.81	574.74	718.39
Daman & Diu	1200.6	1434.93	684.29	669.02
Lakshadweep	1327.77	1458.69	756.77	680.10
All India	972	1407	554	656

Sources (a) Poverty lines—Government of India (2014); (b) Food insecurity lines—Calculated by the authors from IHDS-II

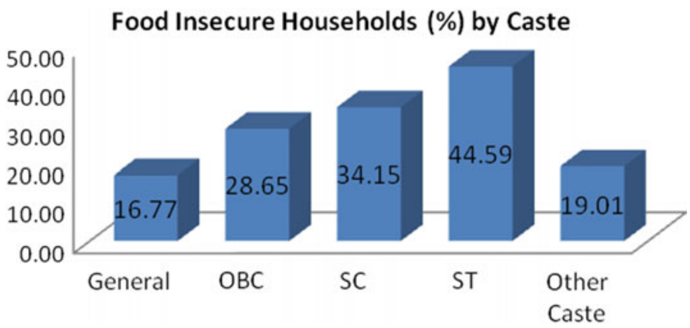

Fig. 1 Food insecure households (%) by caste. *Source* Calculated by authors from IHDS-II

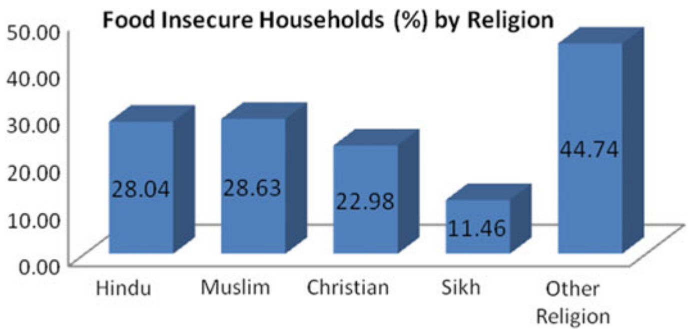

Fig. 2 Food insecure households (%) by religion. *Source* Calculated by authors from IHDS-II

found to be food insecure. The highest food insecurity is found to be in Chhattisgarh with 58% of its sample households being food insecure. This is followed by Meghalaya (52.24%). Other states with food insecurity higher than the national average are Uttar Pradesh (30.15%), Uttarakhand (32.48%), Maharashtra (33.48%), Tamil Nadu (34.91%), Madhya Pradesh (37.98%), Jharkhand (40.45%), Bihar (43.24%) and Odisha 45.77%).

4 The Model

The main focus of this study is to examine the impact of weather shock on household level food insecurity and also to identify other determinants of food insecurity. In order to accomplish this objective a binary logistic regression model is used details of which are shown below. The model is as follows:

$$FI_i = \frac{1}{1 + e^{-(\beta' X_i' + u_i)}}$$

Table 2 Spatial variations in food insecurity in India

States/UT	Food insecurity[a]
All India	27.68
Goa	0
Tripura	0
Puducherry	2.80
Chandigarh	3.53
Nagaland	3.64
Jammu & Kashmir	4.44
Daman & Diu	10.17
Mizoram	11.54
Punjab	12.16
Arunachal Pradesh	13.84
Delhi	14.91
Manipur	17.05
Gujarat	18.21
Sikkim	18.69
Andhra Pradesh	20.47
Himachal Pradesh	20.66
West Bengal	21.11
Karnataka	21.39
Haryana	22.04
Rajasthan	23.01
Assam	24.72
Dadra & Nagar Haveli	25.00
Kerala	25.61
Uttar Pradesh	30.15
Uttarakhand	32.48
Maharashtra	33.48
Tamil Nadu	34.91
Madhya Pradesh	37.98
Jharkhand	40.45
Bihar	43.24
Odisha	45.77
Meghalaya	52.24
Chhattisgarh	58.23

Source Calculated by the authors from IHDS-II
Note [a]Food insecurity represents %age of food insecure sample households

$$FI_i = \frac{1}{1 + e^{-Z}} \tag{1}$$

where,

$$\begin{aligned} Z = \beta_0 + \beta_1 WS_i + \beta_2 PCI_i + \beta_3 HS_i + \beta_4 DR_i + \beta_5 Remit_i \\ + \beta_6 Pov_i + \beta_7 Cultivation_i + \beta_8 FAE_i \\ + \beta_9 Ur_i + \beta_{10} Hindu_i + \beta_{11} OBC_i + \beta_{12} SC_i + \beta_{13} ST_i + \beta_{14} OC_i + u_i \end{aligned} \tag{2}$$

Here FI_i represents food insecurity status of the ith household, which takes value 1 if a household is food insecure and 0 otherwise. $X^{/}$ is a vector of the explanatory variables, $\beta^{/}$ is a vector of the coefficients to be estimated, u_i refers to the disturbance term, and i(i = 1,2, … n) refers to the households. The explanatory variables used in the model are—weather shock (WS), per capita income (PCI), household size (HS), dependency ratio (DR), remittances (Remit), poverty (Pov), cultivation as the main occupation (Cultivation), female adult education (FAE), residence (Ur), religion (Hindu), social category (OBC, SC, ST and OC—General as reference category). The definitions and description of the explanatory variables are explained below.

Weather shock—either in the form excessive or deficient rainfall than normal rainfall—can significantly affect crop output, rural income, prices of essential crops, and thereby make people more susceptible to food insecurity. Therefore, we have taken weather shock (*WS*) as an explanatory variable in the regression model. We have measured it as the percentage deviation of rainfall from the long run average rainfall of a particular district where a particular sample household lives. It is expected that higher the amount of rainfall deviation or weather shock, more will be the probability of the households to be food insecure for the reasons mentioned above.

Income is one the factors that determine capacity of a household to have access to food. Hence, we have used per capita income (*PCI*) of a household—obtained by dividing its total annual income by the number of household members—as another explanatory variable. Higher the per capita income, higher will be the capacity of the household to consume food items. Thus, per capita income is expected to have a negative impact on food insecurity.

Size of a household is another factor that can affect food insecurity. Larger sized households have more mouths to feed and hence have lesser availability of food consumption per capita. Therefore, household size (*HS*) or number of members in a household is taken as another explanatory variable. An increase in household size increases the probability of its food insecurity.

Dependency ratio (*DR*) is another factor that can affect food insecurity of a household. It is defined as the number of young and old dependents as a percentage of working age group members of a household. If dependency ratio is high, there will be more pressure on a household to feed relatively more people by a smaller number of earners in a household. This will reduce the economic capacity of a household to buy enough food for its members. Thus dependency ratio is expected to increase food insecurity.

To capture the impact of remittances on food insecurity a dummy variable (*Remit*) is used which takes the value '1' if a household receives remittances, '0' otherwise. It is expected that remittances into a household reduce its likelihood to be food insecure. This is because receipt of remittances enhances liquidity and hence the household can spend more on food.

Poverty is an important determinant of food insecurity. To capture the impact of poverty on food insecurity a dummy variable (*Pov*) is used which takes the value '1' if household is poor, '0' otherwise. It is expected that the poor do not have enough resources to purchase the required amount of food items for their household which raises their probability of being food insecure.

Cultivation as the main occupation is another determinant of food insecurity. To capture this variable a dummy variable (*Cultivation*) is used, which takes the value '1' if a household's main occupation is cultivation, '0' otherwise. This implies that the household whose main occupation is cultivation are less likely to be food insecure than others. This is quite intuitive. The cultivator households in India are primarily subsistence farmers, and hence allocate a considerable amount of farm produce on household consumption.

The female adult household members in India take the responsibility of preparing and distributing food among other members. Hence, as their level of education increases they become more aware about the importance of nutritious contents of food. Thus, with improvements in their education expenditure by the households on diverse food items containing calorie, proteins and fats also increases, thereby reducing food insecurity. Therefore, female adult education (*FAE*), defined as the highest educational attainment in years among the female adult members of a household is taken as an explanatory variable.

Residence of the households can also be an important determinant of food insecurity. To capture this variable, a dummy variable (*Ur*) is used which takes the value of '1' if a household belongs to urban area and '0' otherwise. In the rural areas, most of the people are associated with agriculture and the farmers are mostly subsistence farmers. Hence, they are likely to be relatively more food secure than their urban counterparts, given the other factors.

To capture the differential impact of different castes on household level food insecurity, four dummy variables are used. The dummy variable *OBC* takes the value of '1' if a household belongs to other backward classes, '0' otherwise. Similarly, $SC = 1$ if a household belongs to scheduled caste category, '0' otherwise. $ST = 1$ if a household belongs to scheduled tribe category, '0' otherwise. $OC = 1$ if a household belongs to other castes, '0' otherwise. Here General caste is taken as reference category. Similarly, a dummy variable (*Hindu*) is also used to capture the differential impact of religion on food insecurity, which takes the value '1' if the household belongs to Hindu religion, and '0' otherwise.

The summary statistics of the explanatory variables are shown in Table 3. As seen from Table 3, the rainfall for the year 2012, i.e., the year to which our study is related, is around 24.10% deficient than the long run average rainfall. An average sample household consists of five members. The average income of the sample households is INR 29,402. From the table, it is also seen that 76% of the household

Table 3 Descriptive statistics of the explanatory variables

Non-categorical variables	Unit	Mean	Std. dev.	Min.	Max.
Weather shock (WS)	Percentage	−24.10	36.74	−99.67	145.58
Household size (HS)	Number	4.85	2.32	1	33
Per capita income (PCI)	INR	29,402	53,996	−2,89,008	41,61,000
Dependency ratio (DR)	Percentage	76.09	74.42	0	80

Categorical variables	Definition	% age
Poor (Pov)	= 1 for sample households who are poor, 0 otherwise	16.41
Urban (Ur)	= 1 for sample households who live in urban areas, 0 otherwise	34.57
Other Backward Classes (OBC)	= 1 for sample households who belong to OBC category, 0 otherwise	40.46
Scheduled Castes (SC)	= 1 for sample households who belong to SC category, 0 otherwise	21.21
Scheduled Tribes (ST)	= 1 for sample households who belong to ST category, 0 otherwise	8.64
Other Caste (OC)[a]	= 1 for sample households who belong to other category (excluding General caste), 0 otherwise	1.34
Religion (Hindu)	= 1 for Hindu sample households, 0 otherwise	81.61
Remittance (Remit)	= 1 if a household receives remittance, 0 otherwise	13.28
Main occupation (Cultivation)	= 1 if the main occupation of a household is cultivation, 0 otherwise	24.41

Note [a]Excluding General Caste, which is taken as the reference category

members are economically dependents. In our sample, 16.41% sample households are found to be poor and 34.57% are living in urban areas. As regards caste wise distribution of the households, 40.46% belong to OBC category, 21.21% belong to SC category, 8.64% belong to ST category and 1.34% are in the others (excluding General) and the remaining belong to General caste. The proportion of sample households belonging to Hindu religion is 81.61%. From the table, it is also seen that only 13.28% sample households have received remittances and 24.41% sample households' main occupation is cultivation.

5 Regression Results

The results of the binary logistic regression of food insecurity are shown in Table 4. Here the odds ratios are reported rather than the coefficients, and the results are interpreted accordingly.[2] It may be noted that the coefficients of all the explanatory variables except other caste (*OC*) is statistically significant which implies that they have statistically significant impacts on our dependent variable.

The odds ratio of weather shock (*WS*) has turned out to be more than 1 which signifies a positive impact of weather shock on the probability of food insecurity. This implies that if deviations from normal rainfall in an area increase, then the households belonging to that area tend to be more food insecure. This is quite obvious because weather shocks, either in the form of excessive rainfall or deficient rainfall, are harmful for the agriculture sector which reduces output.

Table 4 Results of the binary logistic regression

Explanatory variables	Odds ratio	Std. error
Weather shock (*WS*)	1.003***	0.000
Per capita income (*PCI*)	0.999***	0.001
Household size (*HS*)	1.203***	0.008
Dependency ratio (*DR*)	1.158***	0.022
Remittances (*Remit*)	0.921*	0.042
Poor (*Pov*)	12.512***	0.481
Main occupation (*Cultivation*)	0.784***	0.028
Female adult education (*FAE*)	0.989***	0.003
Residence (*Ur*)	1.076**	0.039
Religion (*Hindu*)	1.200***	0.047
Other backward classes (*OBC*)	1.494***	0.058
Scheduled castes (*SC*)	1.634***	0.073
Scheduled tribes (*ST*)	2.091***	0.119
Other castes (*OC*)	1.040	0.146
Const	0.097***	0.006
Pseudo R squared	28.94%	
LR $chi^2(15)$	12326.82	
Prob > chi^2	0.0000***	
Observations	35301	

Note ***, ** and * represent significant at 1%, 5% and 10% respectively

[2]This is because there is a direct relationship between the two. Odds ratios greater than 1 and less than 1 imply positive and negative coefficients respectively. Therefore, our analysis is carried out in terms of odds ratio as it is easier to interpret the impact of the explanatory variables in terms of odds ratio.

The odds ratio of residence (*Ur)* has turned out to be greater than one. This implies that the probability of being food insecure is more in the urban areas than in the rural areas. The odds of food insecurity for an urban household are 1.076 times that of its rural counterpart. The reason for rural households being less food insecure is that they are mostly engaged in cultivation as subsistence farmers, and hence they have better availability of food items in the villages.

Household size (*HS*) is found to have a positive impact on food insecurity. This implies that the probability of food insecurity increases with increase in the size of households. Larger sized households have more mouths to feed and hence have lesser availability of food consumption per capita. An increase in household size by one member causes the probability of food insecurity to increase by 20%.

As far as the differential impact of caste on food insecurity is concerned it is found that compared to general caste, food insecurity is more among Other Backward Classes (*OBC*), Scheduled Castes (*SC*) and Schedule Tribes (*ST*). The odds of being food insecure for a household belonging to OBC, SC and ST are 1.49, 1.63 and 2.09 times, respectively, of a general category household. This is quite expected because usually the general category people are economically better-off than other social classes.

The dummy used to capture differential impacts of religions are also found to have significant coefficients. The odds ratios of the *Hindu* have turned out to be 1.20. This implies that households belonging to the *Hindu* religion are more likely to be food insecure compared to non-Hindu religions that include Muslim, Christian, Sikh and other religions.

Per capita income (*PCI*) is found to have a negative impact on the probability of household level food insecurity. Its odds ratio turned out to be 0.99. This implies that an increase in per capita income of the households by one rupee reduces its probability of food insecurity by 1%. This is quite expected because an increase in per capita income capacitates a household to have access to a higher amount of food items for its members.

Dependency ratio (*DR*), showing the number of young and adult dependents as a percentage of number of economically active members in the households, is found to increase the probability of food insecurity. The odds ratio of this variable is 1.15 which implies that an increase in dependency ratio by 1% increases the probability of being food insecure by 15%.

Female adult education (*FAE*) is found to have a negative impact on food insecurity with odds ratio of 0.98. This means an increase of one year of schooling of adult female members reduces the probability of food insecurity by 2%. The female adult household members in India take the responsibility of preparing and distributing food among other members. Hence, as their level of education increases they become more aware about the importance of nutritious contents of food. Thus, with improvements in their education expenditure by the households on diverse food items containing calorie, proteins and fats also increases, thereby reducing food insecurity.

The odds ratio of *Cultivation* is found to be 0.78. This implies that the households whose main occupation is cultivation are less likely to be food insecure than others. This is quite intuitive. The cultivator households in India are primarily subsistence farmers, and hence allocate a considerable amount of farm produce on household consumption.

The odds ratio for remittances (*Remit*) has turned out to be 0.92. This implies that remittances into a household reduce its likelihood to be food insecure. More precisely, the households receiving remittances are 8% less likely to be food insecure than others. This is because receipt of remittances enhances liquidity and hence the household can spend more on food.

The odds ratio of *Pov* is found to be as high as 12.51. This implies that the probability of food insecurity for the poor households is higher than others. Food insecurity of a poor household is 12.51 times of a non-poor household. This is quite intuitive. The poor do not have enough resources to purchase the required amount of food items for their household which raises their probability of being food insecure. Finally, the Pseudo R squared is found to be reasonably high at 28.94%.

6 Conclusion

This chapter makes a novel attempt to examine food insecurity in India and its variations across space and different social and religious groups. Around 28% of the household in the country are found to be food insecure with large scale variations across the states and union territories. The percentage of food insecure sample households in the country is found to be varying between 0% in Goa and Tripura, and 58% in Chhattisgarh. There is prevalence of large scale inequality in food insecurity among various social and religious groups. Around 45% of the households belonging to scheduled tribes are food insecure and the corresponding figure for general category households is 17%. Likewise, around 11% of the Sikh households are food insecure and the same for religions other than Hindu, Muslims, Christians and Sikhs are as high as 45%.

This chapter further examines the impact of weather shock on household level food insecurity and explores the socio-economic determinants of the same. The results of our analysis reveals that rainfall deviations from normal rainfall, which is used as a proxy of weather shocks, have a positive impact on the probability of a household to be food insecure. Moreover, size of households, dependency ratio, poverty and urban residence make a household more likely to be food insecure. On the other hand, per capita income, female adult education, remittances and cultivation as the main occupation reduce the probability of food insecurity.

Appendix 1

See Table 5.

Appendix 2

Estimation of National and State-specific Food Insecurity Lines
The report of the Expert Group (Rangarajan) to the Planning Commission (Government of India 2014) has outlined the normative requirements of expenditures on food comprising calories, proteins and fats. This recommended expenditures (per capita per month) amount on calories, proteins and fats are used as the benchmark for measuring food insecurity in this study. Thus, the national food insecurity lines have been defined as the monthly per capita food expenditure (calorie + protein + fat) of Rs. 554 in rural areas and Rs 656 in urban areas. These national food insecurity lines are then adjusted as follows to estimate state specific food insecurity lines (separately for rural and urban areas) so as to capture spatial variations in the price level.

The ratio of price index of a state to the national average is worked out as follows. Suppose, the price index of Assam is P_A and that of India is P_I. The poverty line of Assam (PL_A) can be thought of as the national poverty line (PL_I) adjusted by the ratio of price index of Assam to price index of India. Thus,

$$PL_A = PL_I \cdot \frac{P_A}{P_I} \tag{3}$$

$$\frac{P_A}{P_I} = \frac{PL_A}{PL_I} \tag{4}$$

Thus the ratios of state-specific poverty lines to the national poverty line give the price ratios for different states. From Eq. 3 it is seen that multiplication of the national poverty line by the state specific price ratio yields the state specific poverty lines. The same way, state-specific food insecurity line is calculated by multiplying the national food insecurity line by the respective state specific price ratio, where the price ratio is obtained by dividing the state specific poverty line by the national poverty line, as shown by Eq. 4.

Table 5 Composition of the sample households

States/UT	Rural	Urban	Total
Jammu & Kashmir	413	307	720
Himachal Pradesh	1163	313	1476
Punjab	1177	525	1702
Chandigarh	0	85	85
Uttarakhand	287	181	468
Haryana	1497	309	1806
Delhi	21	878	899
Rajasthan	1859	848	2707
Uttar Pradesh	2704	1120	3824
Bihar	1085	462	1547
Sikkim	24	83	107
Arunachal Pradesh	114	45	159
Nagaland	72	38	110
Manipur	42	46	88
Mizoram	54	24	78
Tripura	174	46	220
Meghalaya	106	28	134
Assam	700	291	991
West Bengal	1290	1145	2435
Jharkhand	492	361	853
Orissa	1506	552	2058
Chhattisgarh	1013	311	1324
Madhya Pradesh	2514	609	3123
Gujarat	1100	795	1895
Daman & Diu	59	0	59
Dadra + Nagar Haveli	39	21	60
Maharashtra	2207	1102	3309
Andhra Pradesh	1355	848	2203
Karnataka	2708	1157	3865
Goa	110	78	188
Kerala	724	846	1570
Tamil Nadu	909	1073	1982
Pondicherry	61	46	107
Total	27,579	14,573	42,152

Source IHDS-II, 2011–12

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Statistical Modelling and Variable Selection in Climate Science

Shalabh and Subhra Sankar Dhar

Abstract Several modelling techniques are used in Statistics to obtain different models. The method of linear regression analysis is explained in this article. Several steps starting from concepts, calculation, and interpretation, which are involved in the modelling process are stepwise explained. The role of ridge regression for choosing important explanatory variable affecting the outcome is discussed and is used in the development of LASSO (least absolute shrinkage and selection operator) technique. How to find the linear regression model and the subset of important variables using LASSO with an open source *R* statistical software are illustrated.

Keywords Linear regression model · Variable selection · Model fitting · Ridge regression · LASSO · Prediction

1 Introduction

Climate and climate science have become important areas of research during the past decade. This area is intrinsically connected to the survival of living being on this planet. Nobody can disregard the claim that nature is supreme and has its own laws to govern the earth. However, in spite of this, human beings are the only creation of nature who initiated the thought process to understand its rules and phenomenon. Surely, the nature will never appear before the human being to provide explanations about its regulations. Nevertheless, the human being never lost the spirit for learning and attempted to understand the laws and phenomenon of nature by understanding the various causal factors and variables by moving in the opposite direction. This direction is to first observe the phenomenon in terms of happenings or non-happening of events and collect quantified observations on the variables responsible for inputs

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and outcomes of the phenomenon and events. This step provided a giant leap in the knowledge discovery in understanding the nature, and hence, the climate. For example, the cutting of trees is a factor, which significantly affects the rain but the size of tyre of a vehicle cannot influence the rain. Similarly, an excellent urban planning can change the average atmospheric temperature of a city; more plantation of trees and vegetation can decrease the average atmospheric temperature; how the atmospheric pressure, temperature, wind speed, etc. can affect or forecast the rainfall or climate change, etc. The question here is that how do we decide over such conclusions. Just observing the phenomenon and without the support of any quantified scientific analysis will not provide believable information. The role of Statistical Science and its tools become crucial in such a decision-making process and provides a scientific basis to have belief on such conclusive pieces of evidence.

As per Berliner (2003), there are three stages to understand climate change and related uncertainties—understanding the natural climate variability, experimentation and using primary information sources through observations. Various attempts have been made in the literature to construct climate models using multiple statistical strategies and an important aspect in the climatic research is its statistical modeling. Suppose that the outcome of any experiment or phenomenon depends on input variables. The modeling aims at determining the mathematical functional relationship between the output and input variables. Various statistical techniques are available, which provide statistical modeling from different perspectives, viz., parametric, non-parametric, Bayesian, frequentist, etc. for linear as well as nonlinear models. Various methodologies have been proposed in the statistical literature to obtain a model based on a given set of data on input and output variables. Among them, linear regression analysis is a popular technique, which uses the data on input and output variables to find a linear model.

The first step in any modelling is to identify the variables, which are causing or affecting the outcome of a phenomenon. Usually, there are many variables, which affect the outcome in climate science. Some of those variables are more important in the sense that they explain the variability in the outcome better than the other variables. Also, whenever an experimenter tries to find a model, the aim is to find out a model, which is as close as possible to the outcomes in the real world. Due to this overenthusiasm, the experimenter considers a large number of variables and collects observations on them. Obviously, considering a large number of variables results in more cost of experimentation, time, labour and finally more complications in computations. Such a problem can be avoided by considering only those "important" variables, which are contributing significantly in understanding and explaining the variation in the model as well as avoiding less "important" variables. In the context of linear regression modelling, several methodologies like forward selection, backward elimination, stepwise regression, etc. are popularly used, but they are useful when the number of variables affecting the outcome is not too large. Such classical approaches do not work satisfactorily when the number of variables affecting the variables is large. The approach of LASSO (least absolute shrinkage and selection operator), proposed by Tibshirani (1996) (see also Hastie et al. 2009, 2015) attempted to solve the issue of selecting the subset of "important" variables from a pool of all possible variables. The solutions of such an approach are algorithm and computational based. The idea behind the LASSO was motivated by ridge regression in which some penalty is imposed on the regression coefficients, which can discriminate the regression coefficients that are close to zero and away from zero.

The statistical software plays a vital role in computing the mathematical functions and finding out the statistical models. Nowadays, the statistical analysis is performed with the help of various paid and free software. Among them, the open source *R* software (available at www.r-project.org) has gained popularity in the last decade. An advantage of this software is that it is a free software, and the researchers can contribute their own created packages, which can be downloaded by other researchers to use them.

We have addressed and illustrated how to initiate the linear regression modelling and subset selection using LASSO based on the available set of data. The basic concepts of linear regression modelling and subset selection through LASSO are explained and an attempt is made to keep the level of involved mathematics as low as possible. The objective is to familiarize the users with regression techniques to enable them to be confident to use it and improve their models. The main steps in any regression modelling and subset selection using LASSO technique are explained and illustrated using a small data set using *R* software. The area of linear regression analysis is vast and involves many aspects to be considered before arriving at the final model. Addressing of all such issues is not the aim of this chapter. Many books are available in literature who will give in-depth knowledge of these topics and the more interested reader is referred to books by Rao et al. (2008), Montgomery et al. (2012), Draper and Smith (2014), Heumann et al. (2016) etc.

The plan of this chapter is as follows. The concepts and tools of multiple linear regression modelling are explained in Sect. 2 and its six subsections. A dataset is considered and the implementation of the tools developed in Sect. 3 is demonstrated using the *R* software. Section 4 discusses the role, issues, and the implications of having a large number of explanatory variables in the model followed by a discussion on the role of ridge regression in Sect. 5. Section 6 discusses the LASSO regression and its role in the selection of a subset of "important" explanatory variables followed by the data-based example using the *R* software. Last Sect. 7 presents some conclusions followed by Bibliography.

2 Multiple Linear Regression Modelling

Consider a situation, where the output of a variable, called as dependent variable or study variable depends upon several input variables, called as covariates, regressors or explanatory variables and such relationship is linear in nature. Various graphs between and dependent and independent variables help in confirming the linear relationship. A model consists of variables and parameters, and finding the model is equivalent to finding the values of the involved parameters. The technique of linear regression consists of collection of data on input and output variables and finds the statistical relationship between them.

2.1 Model Description

Let the outcome of an experiment, denoted by dependent or study variable y, depends upon k variables $X_1, X_2, \ldots, X_k$, called as covariates or explanatory variables. The experiment is conducted n times by assigning different values to $X_1, X_2, \ldots, X_k$ as $X_1 = x_{1i},\ X_2 = x_{2i}, \ldots, X_k = x_{ki},\ i = 1, 2, \ldots, n$ and respective observations on the outcome $y_1, y_2, \ldots, y_n$ are obtained. So ith set of observation (numerical values) is represented as $(y_i, x_{1i}, x_{2i}, \ldots, x_{ki}),\ i = 1, 2, \ldots, n$. Let the joint relationship between y and $X_1, X_2, \ldots, X_k$ is linear with respect to the parameters $\beta_1, \beta_2, \ldots, \beta_k$ in the sense that $\frac{\partial E(y)}{\partial \beta_j}$ does not depend on any of the β's and is described as

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon, \tag{1}$$

which is satisfied by each set of observations $(y_i, x_{1i}, x_{2i}, \ldots, x_{ki}),\ i = 1, 2, \ldots, n$ as

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_k x_{ki} + \varepsilon_i. \tag{2}$$

In practice, many random factors affect the collection of data sets $(y_i, x_{1i}, x_{2i}, \ldots, x_{ki}),\ i = 1, 2, \ldots, n$ which may violate the equality sign in the exact joint relationship between y and $X_1, X_2, \ldots, X_k$. To take care of the effects of random factors, a random error or disturbance term ε is introduced in the model (1), which absorbs the random effects that are present in every set of observation through (2) and ensures an equality sign in (1). This model (1) is called a multiple linear regression model with k covariates, and the parameters $\beta_j\ (j = 0, 1, \ldots, k)$ are called the regression coefficients. In particular, β_0 is called as an intercept term and $\beta_1, \beta_2, \ldots, \beta_k$ are called as slope parameters. This model describes a hyperplane in the k-dimensional space of the explanatory variables X_j.

It is more convenient to deal with the multiple regression models when the variables and the observations on them are expressed in matrix notations. This allows a very compact display of the model, data, and results. In matrix notation, the model is obtained by combining the n equations with k explanatory variables in (1) as

$$y = X\beta + \varepsilon, \tag{3}$$

where $y = (y_1, y_2, \ldots, y_n)^T$ is a $n \times 1$ vector of n observation on dependent or study variable;

$X = \begin{pmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1k} \\ 1 & x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & \cdots & x_{nk} \end{pmatrix}$ is a $n \times (k+1)$ design matrix of n observations on each of the k explanatory variables arranged in n rows and $(k + 1)$ columns corresponding to intercept term and k covariates, $\beta = (\beta_0, \beta_1, \beta_2, \ldots, \beta_k)^T$ is a $(k + 1) \times 1$ vector of regression coefficients, and $\varepsilon = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n)^T$ is a $n \times 1$ vector of random error components or disturbance term.

Some assumptions are required in the model (3) for the implementation of statistical methods and to study the statistical properties of estimators of regression coefficients. It is assumed that $E(\varepsilon) = 0$ (i.e., mean of random errors is zero), $E(\varepsilon\varepsilon^T) = \sigma^2 I_n$ (i.e., the random errors are identically and independently distributed having constant variance σ^2), X is a full column rank non-stochastic (or fixed) matrix, and $\varepsilon \sim N(0, \sigma^2 I_n)$ (i.e., the random errors are following a n dimensional multivariate normal distribution with mean vector 0 and covariance matrix $\sigma^2 I_n$). Note that operator E is called as Expectation, e.g., $E(\varepsilon)$ is called as expected value of ε, which represents the arithmetic mean of value of all ε in the population. Another assumption is $\lim_{n\to\infty} \left(\frac{X^T X}{n}\right) = \Delta$ exists, and it is a non-stochastic and nonsingular matrix (with finite elements). Such an assumption is required to study the large sample asymptotic properties of the estimators. The explanatory variables can also be stochastic in some cases but they are assumed to be fixed in this article.

Next, we discuss the interpretation of different regression parameters $\beta_j (j = 0, 1, \ldots, k)$ involved in the multiple regression model. Note that

$$E(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k. \tag{4}$$

We observe that the partial derivative of mean value of y, i.e., $E(y)$ with respect to jth explanatory variable X_j, i.e. $\frac{\partial E(y)}{\partial X_j} = \beta_j$, $j = 1, 2, \ldots, k$ represents the expected or average change in the response y with respect to unit change in X_j, i.e., how much the average value of y will change when the value of X_j is changed by one unit. When $X_j = 0$, $j = 1, 2, \ldots, k$ then $E(y) = \beta_0$ that indicates the average value of y when all the observations on all the explanatory variables are assigned zero values. Another involved parameter is σ^2, which measures the variation in the random error term. It indicates the degree of variability present in the observed responses $y_1, y_2, \ldots, y_n$.

First, we understand that what is needed to know or find a model based on a given set of data on study and explanatory variables. A model is a functional relationship between y and $X_1, X_2, \ldots, X_k$. The functional form is unknown and described by its parameters, which are also unknown. An attempt is made to know a possible form of the functional relationship and then the involved parameters are needed to be found based on a given set of data obtained from studies and experiments. Once we come to know the values of the parameters, a functional mathematical relationship is established between the input and output variables giving rise to a model. Though the exact functional relationship between y and $X_1, X_2, \ldots, X_k$ is unknown, but over specific ranges of the explanatory variables, the linear regression model is an adequate approximation to the true unknown functional relationship. Multiple linear regression models are often used as empirical models or approximating functions to describe the relationship between the input and output variables.

Finding a complete model involves various steps and issues. The first step is to assume the possible functional relationship between y and $X_1, X_2, \ldots, X_k$. Next step is to use an appropriate statistical estimation technique to find out the values of involved parameters as point estimates and/or interval estimates. This is followed by the test of hypothesis for the estimated parameters. Then the goodness of fitted model is checked. In between, some other issues crop up in this process, e.g., how to know if the model obtained is good or not, the variables $X_1, X_2, \ldots, X_k$ are relevant or not, the choice of k, i.e., the number of relevant variables, etc. Addressing such issues adequately is also a part of modelling. For example, changing the value of k will change the values of parameters, and consequently, the decision on the test of hypothesis about the parameters, goodness of fit, etc. may also be altered. This will result into a new model. Moreover, all the aspects are interrelated, and usually, a good model cannot be obtained in a single shot. Instead, it is a recursive process and continues until the experimenter is satisfied with the model in the sense that the model is representing the real world phenomenon as close as possible.

2.2 *Point Estimation of Parameters*

The problem of knowing the unknown parameters based on a given set of data can then be formulated as finding a "good" value for the coefficient vector β, which is the unknown parameter to be estimated from the given data. There are various methods of estimation available in the literature, which gives rise to different forms of the estimators. We use the ordinary least square method for finding out the value of the parameters, i.e., parameter estimation. This provides the values of the parameters as a point estimate, i.e., a single value. A general procedure for the estimation of the regression coefficient vector is to minimize the random errors as

$$\sum_{i=1}^{n} f(\varepsilon_i) = \sum_{i=1}^{n} f(y_i - \beta_0 - x_{i1}\beta_1 - x_{i2}\beta_2 - \cdots - x_{ik}\beta_k) \tag{5}$$

for a suitably chosen function *f*. Another well known choice of f is $f(\varepsilon) = |\varepsilon|$ leading to the least absolute deviation estimator. We consider the principle of least square, which is associated with $f(\varepsilon) = \varepsilon^2$. We minimize the sum of squared errors ε_i's in $Y = X\beta + \epsilon$, i.e.,

$$S(\beta) = \sum_{i=1}^{n} \varepsilon_i^2 = \varepsilon^T \varepsilon = (y - X\beta)^T (y - X\beta) \tag{6}$$

for the given observations on y and X, and this provides a point estimator of β, denoted by $\hat{\beta}$ as

$$\hat{\beta} = (X^T X)^{-1} X^T y, \tag{7}$$

where $\hat{\beta} = (\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, \dots, \hat{\beta}_k)^T$ is a vector that provides numerical values to unknown $\beta = (\beta_0, \beta_1, \beta_2, \dots, \beta_k)^T$ using the observations $y = (y_1, y_2, \dots, y_n)^T$ and $X = \begin{pmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1k} \\ 1 & x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & \cdots & x_{nk} \end{pmatrix}$. This is called as ordinary least squares estimator (OLSE) of β.

The estimator $\hat{\beta}$ is an unbiased estimator of β in the sense that

$$E(\hat{\beta}) = \beta, \tag{8}$$

and its covariance matrix is given by

$$V(\hat{\beta}) = E(\hat{\beta} - \beta)(\hat{\beta} - \beta)^T = \sigma^2 (X^T X)^{-1}. \tag{9}$$

Note that the covariance matrix (9) depends upon σ^2, which is unknown. So it is estimated as

$$\hat{\sigma}^2 = \frac{(y - X\hat{\beta})^T (y - X\hat{\beta})}{n - (k+1)} = \frac{y^T [I - X(X^T X)^{-1} X^T] y}{n - (k+1)} \tag{10}$$

Note that the meaning of the "estimated" is that the value of the concerned quantity can be found using the available observations. Then the covariance matrix (9) is estimated as

$$\widehat{V(\hat{\beta})} = \hat{\sigma}^2 (X^T X)^{-1}. \tag{11}$$

Let C_{jj} and $C_{jj'}$ denote the diagonal and off-diagonal elements of $(X^T X)^{-1}$, respectively. The diagonal elements of matrix in (11) provides the values of estimated variances of $\hat{\beta}_j$'s, $j = 0, 1, 2, \dots, k$. The off-diagonal elements in matrix in (11) provide the values of estimated covariance $\text{cov}(\hat{\beta}_j, \hat{\beta}_{j'})$, $j \neq j' = 1, 2, \dots, k$. The positive square root of values of estimated variances of $\hat{\beta}_j$'s, $j = 0, 1, 2, \dots, k$ is called as their standard errors and is denoted by $se(\hat{\beta}_j) = \sqrt{\hat{\sigma}^2 C_{jj}}, \;\; j = 0, 1, 2, \dots, k$. The standard error gives an idea about the variation of estimates of $\hat{\beta}_j$'s. Smaller the value of standard errors, better is the estimator.

The estimator $\hat{\sigma}^2$ is an unbiased estimator of σ^2 in the sense that

$$E(\hat{\sigma}^2) = \sigma^2. \tag{12}$$

The estimators $\hat{\beta}$ in (7) and $\hat{\sigma}^2$ in (10) are the point estimators of β and σ^2 respectively based on ordinary least squares estimation. They are called as ordinary least squares estimators of β and σ^2.

Just like the ordinary least squares estimation, there is another method to estimate the unknown parameters, called as maximum likelihood estimation. If the maximum likelihood estimation method is employed to estimate β and σ^2 based on given observations on y and X, then the maximum likelihood estimates of β and σ^2 are obtained as

$$\tilde{\beta} = (X^T X)^{-1} X^T Y \tag{13}$$

and

$$\tilde{\sigma}^2 = \frac{(y - X\hat{\beta})^T (y - X\hat{\beta})}{n} = \frac{y^T [I - X(X^T X)^{-1} X^T] y}{n}, \tag{14}$$

respectively. Note that the ordinary least squares and maximum likelihood estimates of β are the same whereas the ordinary least squares and maximum likelihood estimates of σ^2 are different. Moreover, the maximum likelihood estimates of β and σ^2 in (13) and (14), respectively remain valid as long as the probability distribution of random error component in (3) remains multivariate normal. If this distribution changes, the maximum likelihood estimates will change.

After obtaining the values of the regression coefficients based on given data, the fitted model is obtained as $y = X\hat{\beta}$. Next, by substituting the values of given explanatory variables in the model $y = X\hat{\beta}$, the values of study variable are obtained as $\hat{y} = X\hat{\beta}$, which are called as fitted values. The fitted values indicate that these values would have been the values of study variable if the values of estimated parameters had been the actual values of the parameters. The difference between the observed values y and fitted values $\hat{y}$ is called as residual given by $e = y \sim \hat{y}$ (symbol ~ denotes the difference). Usually, we consider $e = y - \hat{y} = y - X\hat{\beta}$. In an ideal model, one would expect the residuals to be zero. Residuals help in checking various model assumptions about ε based on a given sample of data. Here $\hat{\beta}$ and $\hat{\sigma}^2$ (or equivalently $\tilde{\beta}$ and $\tilde{\sigma}^2$) are the point estimates of β and σ^2, respectively as they provide the values at points, i.e., the single values.

2.3 Confidence Interval Estimation

The interval estimation provides the value of parameters in an interval, in terms of confidence intervals. The confidence intervals in multiple regression model can be constructed for the individual as well as joint regression coefficients. We consider both of them as follows:

The $100(1 - \alpha)\%$ confidence interval or equivalently the interval estimate of individual regression coefficients β_j $(j = 0, 1, 2, \ldots, k)$ is given by

$$\hat{\beta}_j - t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}} \leq \beta_j \leq \hat{\beta}_j + t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}}, \tag{15}$$

where C_{jj} is the jth diagonal element of $(X^T X)^{-1}$, which means that

$$P\Big[\hat{\beta}_j - t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}} \leq \beta_j \leq \hat{\beta}_j + t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}}\Big] = 1 - \alpha, \tag{16}$$

where $0 \leq \alpha \leq 1$ is the level of significance in the context of test of hypothesis and $1 - \alpha$ is the confidence coefficient, $t_{\frac{\alpha}{2},n-k-1}$ represents the upper $\alpha\%$ points on the t distribution with $(n - k - 1)$ degrees of freedom. The interpretation of a confidence interval is that it provides an interval, where the unknown β_j will lie between $\left(\hat{\beta}_j - t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}}\right)$ and $\left(\hat{\beta}_j + t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}}\right)$ with $100(1 - \alpha)\%$ chances.

Now we discuss the confidence intervals for more than one regression coefficients. A set of confidence intervals that are simultaneously true with probability $(1-\alpha)$ are called simultaneous or joint confidence intervals. A $100(1-\alpha)\%$ elliptically shaped joint confidence region for all of the parameters in β excluding intercept term is given by

$$\frac{(\hat{\beta} - \beta)^T X^T X(\hat{\beta} - \beta)}{k\hat{\sigma}^2} \leq F_\alpha(k, n - k), \tag{17}$$

which means that

$$P\left[\frac{(\hat{\beta} - \beta)^T X^T X(\hat{\beta} - \beta)}{k\hat{\sigma}^2} \leq F_\alpha(k, n - k)\right] = 1 - \alpha, \tag{18}$$

where $F_\alpha(k, n - k)$ represents the upper $\alpha\%$ points on the F distribution with k and $(n - k)$ degrees of freedom.

2.4 *Test of Hypothesis*

The test of hypothesis related to the parameters of model plays a vital role in any statistical modelling and provide different types of relevant information based on the given set of data. Two crucial questions, which are answered for any regression modelling through the test of hypothesis are about the overall adequacy of the model and to find which of the explanatory variables are essential in the sense that they are capable of explaining the variability in the observations on study variable.

The first test is about testing the overall adequacy of the model, which is answered through the analysis of variance (ANOVA). The technique of ANOVA partitions the total variability in the observations on study variable into two orthogonal components. One of the component explains the variability explained by the fitted regression model through the sum of squares due to regression. Another component explains the contribution of random errors through the sum of squares due to errors. The ANOVA tests the null hypothesis $H_0 : \beta_1 = \beta_2 = \cdots = \beta_k = 0$ against the alternative hypothesis $H_1 : \beta_j \neq 0$ for at least one $j = 1, 2, \ldots, k$. Note that the intercept term is not included in H_0. Rejection of the null hypothesis indicates that at least one of the explanatory variables among $X_1, X_2, \ldots, X_k$ is a crucial variable to remain in the model and contributes significantly in the model. The result and outcome of analysis of variance are expressed in an ANOVA table as given:

ANOVA table

Source of variation	Sum of squares	Degrees of freedom	Mean squares	F value
Regression Error	SS_{reg} SS_{error}	k $n-k-1$	$MS_{reg} = \frac{SS_{reg}}{k}$ $MS_{error} = \frac{SS_{res}}{n-k-1}$	$F = \frac{MS_{reg}}{MS_{error}}$
Total	SS_T	$n-1$		

Following notations are used in this ANOVA table:

1. Total sum of squares: $SS_T = \sum_{i=1}^{n}(y_i - \bar{y})^2 = SS_{reg} + SS_{res}$ where $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$.
2. Sum of squares due to residual: $SS_{error} = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2 = y^T\left[I - X(X^TX)^{-1}X^T\right]y$
3. Sum of squares due to regression: $SS_{reg} = SS_T - SS_{res}$.

When $H_0 : \beta_1 = \beta_2 = \cdots = \beta_k$ is true, the statistic $F = \frac{MS_{reg}}{MS_{error}}$ follows an F distribution with k and $(n-k-1)$ degrees of freedom under H_0. The decision rule is to reject H_0 at α level of significance when p-value is smaller than α. The p-value is computed and provided by the software. The p-value is interpreted as the probability of observing results equal to, or more extreme than those actually observed if the null hypothesis was true. A small p-value (usually smaller than α) indicates the decision to reject the null hypothesis. Rejection of H_0 indicates that it is likely that at least one regression coefficient is not equal to zero, say $\beta_j \neq 0$ $(j = 1, 2, \ldots, k)$ and that is why $H_0 : \beta_1 = \beta_2 = \cdots = \beta_k$ is rejected.

In practice, the chances are remote that $H_0 : \beta_1 = \beta_2 = \cdots = \beta_k$ in ANOVA is accepted as this would mean that all the variables are irrelevant. When the null hypothesis is rejected, then the next question is to find the regression coefficient(s) responsible for the rejection of null hypothesis.

Adding irrelevant or deleting important explanatory variables have different consequences in the modelling but in any case, they distort the quality of the fitted model. Thus, an essential objective in regression modelling to choose only the important variables so that the usefulness of the model is not reduced. The test of hypothesis on individual regression coefficients helps in this regard.

So next we consider the test of null hypothesis about individual regression coefficients. To test the null hypothesis $H_0 : \beta_j = 0$ versus the alternative hypothesis $H_1 : \beta_j \neq 0, j = 0, 1, 2, \ldots, k$, the corresponding test statistic is $t = \frac{\hat{\beta}_j}{\sqrt{\hat{\sigma}^2 C_{jj}}}$, which follows a t distribution with $(n - k - 1)$ degrees of freedom under H_0. The decision rule is to reject H_0 at α level of significance if p-value is smaller than α. If $H_0 : \beta_j = 0$ is accepted, then the term $X_j \beta_j$ in (1) becomes $X_j \times 0 = 0$, which indicates as if the jth explanatory variable X_j is absent in the model or in other words, the contribution of X_j is negligible and hence X_j can be treated as an irrelevant variable. Thus this test indicates the contribution of X_j in modelling the relationship given the other explanatory variables in the model.

2.5 *Coefficient of Determination* (R^2) *and Adjusted* R^2

Once a model is fitted based on suitably chosen explanatory variables, it is required to know how good is the fitted model. The quantification of goodness of fit is achieved by the coefficient of determination, which is based on the use of multiple correlation coefficient between y and $X_1, X_2, \ldots, X_k$ denoted as R^2. The square of multiple correlation coefficient (R^2) is called as coefficient of determination, which describes the degree of goodness of fit of the regression line obtained on the basis of a sample of data.

The coefficient of determination is defined as

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2} = \frac{SS_{reg}}{SS_T}, \quad 0 \leq R^2 \leq 1. \tag{19}$$

It is important to note that the R^2 in (19) is defined only when the intercept term is present in the model (1). The value $R^2 = 0$ indicates the poorest fit whereas $R^2 = 1$ indicates the best fit of the model. Any other value of R^2 between 0 and 1 indicates the adequacy of fitted model, e.g., $R^2 = 0.75$ indicates that the model is 75% good or 75% of the variation in y is explained by $X_1, X_2, \ldots, X_k$.

Another version of R^2 is called as adjusted R^2, denoted as $\bar{R}^2$ or adj R^2. It corrects some of the inadequacies of R^2 and is defined as

$$\bar{R}^2 = 1 - \frac{SS_{error}/(n - k)}{SS_T/(n - 1)} = 1 - \left(\frac{n - 1}{n - k}\right)(1 - R^2). \tag{20}$$

Adjusted R^2 has the same interpretations as R^2 and its value will be smaller than the value of R^2. When the model fitting is good, the difference in the values of R^2 and its adjusted version will be very less.

2.6 *Prediction of Values of Study Variable*

Any model is prepared with an objective to use further in other applications. One important application is the prediction. The meaning of prediction in the contest of regression modelling is to know the value of study variable for given values of explanatory variables. The predictions are obtained by first fitting a model based on a given set of data on study and explanatory variables and then finding the value(s) of study variable for given values of explanatory variables.

We aim to predict the unknown value y_0 of y at a given value of explanatory variables $x_0 = (x_{01}, x_{02}, \ldots, x_{0k})^T$. The predictions can be made at a point as well as in an interval. The predictor as a point predictor is given by

$$p_f = x_0^T \hat{\beta} = \hat{\beta}_0 + x_{01}\hat{\beta}_1 + x_{02}\hat{\beta}_2 + \cdots + x_{0k}\hat{\beta}_k, \tag{21}$$

and its variance is estimated by

$$\widehat{Var}(p_f) = \hat{\sigma}^2\big[1 + x_0^T (X^T X)^{-1} x_0\big]. \tag{22}$$

The prediction in an interval is obtained by finding the prediction interval. The $100(1-\alpha)\%$ prediction interval of y_0 at the point x_0 is given by

$$\left(p_f - t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2[1 + x_0^T (X^T X)^{-1} x_0]},\quad p_f + t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2[1 + x_0^T (X^T X)^{-1} x_0]}\right), \tag{23}$$

which means that the predicted value will lie in the interval (23) with $100(1-\alpha)\%$ chances in the sense that

$$P\left[p_f - t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2[1 + x_0^T (X^T X)^{-1} x_0]} \le y_0 \le p_f + t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2[1 + x_0^T (X^T X)^{-1} x_0]}\right]$$
$$= 1 - \alpha.$$

3 Data-Based Example

Consider a data-based example to understand the steps, computation, and interpretation of different quantities involved in deriving a multiple regression model. Another objective is to explain how to read the outcome of software. The format of outcome in different software may vary but the reported quantities are more or less the same.

The rainfall during the monsoon season in a region depends upon several variables and we consider three such variables for illustration viz., wind speed, precipitation and relative humidity. The hypothetical data on monthly rainfall (in cms.), wind speed (in km per hour), precipitation (in %) and relative humidity (in %) are given in Table 1.

Table 1 Data on rainfall, wind speed, precipitation and relative humidity

Observation number (i)	Rainfall (y_i)	Wind speed (x_{1i})	Precipitation(x_{2i})	Relative humidity (x_{3i})
1	122.0	18.3	29.1	52.0
2	114.6	15.7	23.5	50.8
3	135.4	15.7	29.8	65.2
4	136.1	19.5	25.5	64.0
5	135.7	15.4	25.7	68.7
6	119.1	19.7	20.2	50.2
7	128.1	19.2	26.4	57.5
8	126.1	15.1	20.6	64.3
9	125.2	19.6	24.2	53.5
10	137.4	18.2	26.5	67.2

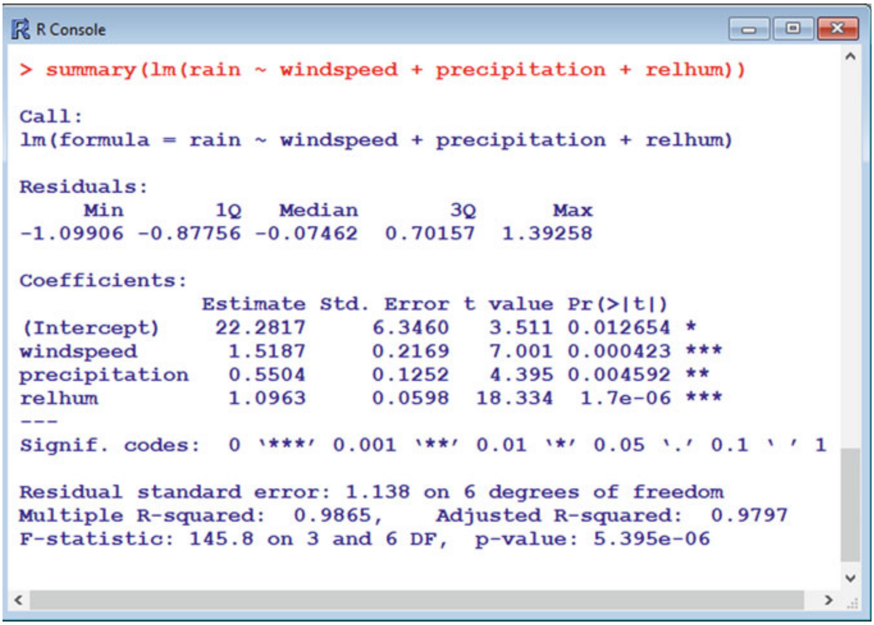
We use the data in *R* software (available at https://www.r-project.org/) to find the relationship of rainfall with wind speed, precipitation, and relative humidity. The variables on rainfall, wind speed, precipitation, and relative humidity are denoted as **rain**, **windspeed**, **precipitation**, and **relhum** respectively. The data on the variables in *R* software is entered as follows:

```
windspeed=c(18.3, 15.7, 15.7, 19.5, 15.4, 19.7, 19.2,
15.1, 19.6, 18.2)
precipitation=c(29.1, 23.5, 29.8, 25.5, 25.7, 20.2,
26.4, 20.6, 24.2, 26.5)
relhum=c(52.0, 50.8, 65.2, 64.0, 68.7, 50.2, 57.5,
64.3, 53.5, 67.2)
rain=c(122.0, 114.6, 135.4, 136.1, 135.7, 119.1, 128.1,
126.1, 125.2, 137.4)
```

The *R* command to fit a linear model is **lm()**. The *R* command **summary(lm(rain ~ windspeed + precipitation + relhum))** is used to fit the multiple linear regression model of **rain** on **windspeed**, **precipitation**, and **relhum**. The outcome of *R* software is copied from the console of software and reproduced as follows:

```
> summary(lm(rain~ windspeed+precipitation+relhum))
Call:
lm(formula = rain ~ windspeed + precipitation + relhum)

Residuals:
     Min       1Q   Median       3Q      Max
-1.09906 -0.87756 -0.07462  0.70157  1.39258

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    22.2817     6.3460   3.511 0.012654 *
windspeed       1.5187     0.2169   7.001 0.000423 ***
precipitation   0.5504     0.1252   4.395 0.004592 **
relhum          1.0963     0.0598  18.334  1.7e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.138 on 6 degrees of freedom
Multiple R-squared:  0.9865,    Adjusted R-squared:  0.9797
F-statistic: 145.8 on 3 and 6 DF,  p-value: 5.395e-06
```

The screen shot of this outcome when executed over the *R* software is as follows:



```
R Console
> summary(lm(rain ~ windspeed + precipitation + relhum))

Call:
lm(formula = rain ~ windspeed + precipitation + relhum)

Residuals:
     Min       1Q   Median       3Q      Max
-1.09906 -0.87756 -0.07462  0.70157  1.39258

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)    22.2817     6.3460   3.511 0.012654 *
windspeed       1.5187     0.2169   7.001 0.000423 ***
precipitation   0.5504     0.1252   4.395 0.004592 **
relhum          1.0963     0.0598  18.334  1.7e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.138 on 6 degrees of freedom
Multiple R-squared:  0.9865,    Adjusted R-squared:  0.9797
F-statistic: 145.8 on 3 and 6 DF,  p-value: 5.395e-06
```

Now we understand the interpretation of this outcome. We want to fit here a model $y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$, where y denotes **rain**, X_1 denotes **windspeed**, X_2 denotes **precipitation**, and X_3 denotes **relhum** for which observations $(y_i, x_{1i}, x_{2i}, x_{3i})$, $i = 1, 2, \ldots, 10$ are available.

Point estimation:
The regression coefficient vector $\beta = (\beta_0, \beta_1, \beta_2, \beta_3)'$ is estimated by $\hat{\beta} = (\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, \hat{\beta}_3)^T = (22.2817, 1.5817, 0.5504, 1.0963)^T$ as in (7) is given under the **`Coefficients`** in the second column **`Estimate`**. The fitted model is thus obtained as

$$y = X\hat{\beta} = \hat{\beta}_0 + X_1\hat{\beta}_1 + X_2\hat{\beta}_2 + X_3\hat{\beta}_3 = 22.2817 + 1.5817X_1 + 0.5504X_2 + 1.0963X_3.$$

The third column under the **`Coefficients`** is **`Std. Error`**, which reports the variances of $\hat{\beta}_0$, $\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_3$, that are obtained from the positive square root of diagonal elements of estimated covariance matrix $\widehat{V(\hat{\beta})} = \hat{\sigma}^2(X^TX)^{-1}$, where $\hat{\sigma}^2 = \frac{(y-X\hat{\beta})^T(y-X\hat{\beta})}{n-(k+1)} = \frac{y^T[I-X(X^TX)^{-1}X^T]y}{n-(k+1)}$ with $n = 10$ and $k = 3$. Also, the value given by **`Residual standard error: 1.138`** provides the value of $\sqrt{\hat{\sigma}^2} = 1.138$.
Test of hypothesis:
The fourth column under the **`Coefficients`** is **`t value`**, which gives the values of $t = \frac{\hat{\beta}_j}{\sqrt{\hat{\sigma}^2 C_{jj}}}$ to test the null hypothesis about individual regression coefficients $H_0 : \beta_j = 0, (j = 0, 1, 2, 3)$ versus the alternative hypothesis $H_1 : \beta_j \neq 0$. Let the chosen level of significance is at 5%, i.e., $\alpha = 0.05$. The fifth column under the **`Coefficients`** is **`Pr(>|t|)`**, which gives the p-values corresponding to $H_0 : \beta_j = 0$. For example, the t values for $H_0 : \beta_0 = 0$ (for intercept) is 3.511, and its corresponding p-value is 0.012654, which is less than the level of significance $\alpha = 0.05$. This indicates that $H_0 : \beta_0 = 0$ is rejected. Similarly, the t values for $H_0 : \beta_1 = 0$ (**`windspeed`**) is 7.001, and its corresponding p-value is 0.000423, which is less than the level of significance $\alpha = 0.05$. This indicates that $H_0 : \beta_1 = 0$ is rejected meaning thereby that the variable “windspeed” is an important variable and is contributing in explaining the variation in “rainfall”. The t values for $H_0 : \beta_2 = 0$ (**`precipitation`**) and $H_0 : \beta_3 = 0$ (**`relative humidity`**) are 4.395 and 18.334, respectively, and the corresponding p values are 0.004592 and 1.7×10^{-06}, respectively, which are less than the level of significance $\alpha = 0.05$ indicating that the variables “precipitation” and “relative humidity” are relevant variables. The following outcome

```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

indicates various values of $\alpha = 0.001$, $\alpha = 0.01$, $\alpha = 0.05$, $\alpha = 0.1$, $\alpha = 1$ and stars (`*`) after the p-values indicate the outcome of test of hypothesis in terms of the significance of $H_0 : \beta_j = 0$.
Goodness of fit:
The second last line in the outcome is **`Multiple R-squared: 0.9865`** and **`Adjusted R-squared: 0.9797`**, which provides the values of coefficient of determination R^2 in (19) and adjusted R^2 in (20), respectively. Thus $R^2 = 0.9865$ and $\bar{R}^2 = 0.9797$ indicate that the fitted model is nearly 97–98% “good”.

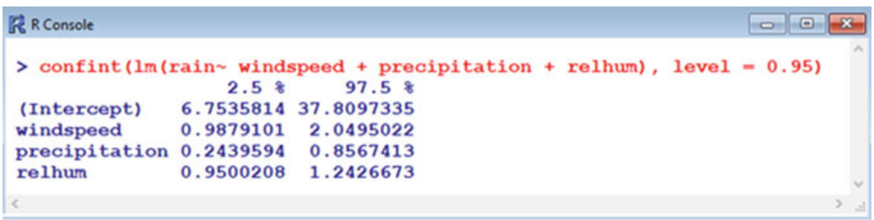
Residuals:
Next, we consider the outcome related to the residuals $e = y \sim \hat{y}$. For example, the fitted value $\hat{y}_1 = \hat{\beta}_0 + x_{11}\hat{\beta}_1 + x_{12}\hat{\beta}_2 + x_{13}\hat{\beta}_3$, which is obtained for given values of x's ($x_{11} = 18.3, x_{12} = 29.1, x_{13} = 52.0$) as $\hat{y}_1 = 22.2817 + 1.5817 \times 18.3(x_{11}) + 0.5504 \times 29.1(x_{12}) + 1.0963 \times 52.0(x_{13}) = 124.251$ and $y_1 = 122.0$, so residual corresponding to the first set of observation is $e_1 = y_1 - \hat{y}_1 = -2.251$. Other values of residuals can be found similarly. The following outcome

```
Residuals:
     Min       1Q   Median       3Q      Max
-1.09906 -0.87756 -0.07462  0.70157  1.39258
```

provides the information on the distribution of the values of residuals in terms of their minimum value (**`Min=-1.09906`**), maximum value (**`Max=1.39258`**), first quartile (**`1Q=-0.87756`**), second quartile (**`Median=-0.07462`**) and third quartile (**`3Q=0.70157`**).
Analysis of variance:
The outcome **`F-statistic: 145.8 on 3 and 6 DF, p-value: 5.395e-06`** gives the value of the F-Statistics $F = \frac{MS_{reg}}{MS_{error}}$ related to the analysis of variance. It tests $H_0 : \beta_1 = \beta_2 = \beta_3 = 0$ against the alternative hypothesis $H_1 : \beta_j \neq 0$ for at least one $j = 1, 2, 3$ with $k = 3$ and $n - k - 1 = 6$ degrees of freedom with corresponding p-value $= 5.395 \times 10^{-06}$, which is less than the level of significance $\alpha = 0.05$. This indicates that $H_0 : \beta_1 = \beta_2 = \beta_3 = 0$ is rejected.
Confidence interval:
The $100(1 - \alpha)\%$ confidence interval of $\beta_j (j = 0, 1, 2, \ldots, k)$ is given by $\hat{\beta}_j - t_{\frac{\alpha}{2}, n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}} \leq \beta_j \leq \hat{\beta}_j + t_{\frac{\alpha}{2}, n-k-1}\sqrt{\hat{\sigma}^2 C_{jj}}$. The 95% confidence intervals with $\alpha = 0.05$ for intercept term and regression coefficients are obtained by the R command **`confint()`** as follows:

```
> confint(lm(rain~ windspeed + precipitation + relhum), level = 0.95)
                  2.5 %     97.5 %
(Intercept)   6.7535814 37.8097335
windspeed     0.9879101  2.0495022
precipitation 0.2439594  0.8567413
relhum        0.9500208  1.2426673
```

The screenshot of this outcome, when executed over the R software, is as follows:



Here **level = 0.95** indicates the value of $1-\alpha = 1-0.05 = 0.95$ and can be changed for the desired value of α. This outcome provides the lower and upper confidence limits of parameters as follows: $6.7535814 \le \beta_0 \le 37.8097335$, $0.9879101 \le \beta_1 \le 2.0495022$, $0.2439594 \le \beta_2 \le 0.8567413$ and $0.9500208 \le \beta_3 \le 1.2426673$. For example, $0.9879101 \le \beta_1 \le 2.0495022$ tells that there are 95% chances that β_1 is expected to lie between 0.9879101 and 2.0495022. Recall that the point estimate of β_1 is 1.5187, which lies within this interval. A smaller length of interval is preferable over a large length of interval.

Prediction:

Next we consider the prediction. Suppose the predictions on rain are to be made for following two sets of observations on wind speed, precipitation, and relative humidity.

Observation number (i)	Wind speed (x_{1i})	Precipitation (x_{2i})	Relative humidity (x_{3i})
1	20	30	55
2	17	25	48

The R command to obtain the predicted values and prediction interval of rain is **predict(), which** gives the following outcome:

```
> predict(lm(rain~ windspeed + precipitation + relhum), newdata =
data.frame(windspeed=c(20,17),precipitation=c(30,25),relhum=c(55,48)),
interval = "prediction")
       fit      lwr      upr
1 129.4652 125.9713 132.9591
2 114.4829 111.0423 117.9236
```

The screenshot of this outcome, when executed over the R software, is as follows:

The first column under **fit** gives the predicted values of rain fall (y) as a point, which are obtained by $p_{f1} = \hat{\beta}_0 + x_{11}\hat{\beta}_1 + x_{12}\hat{\beta}_2 + x_{13}\hat{\beta}_3$ for given values of x's as

$$p_{f1} = 22.2816575{+}1.5187061 \times 20{+}0.5503503 \times 30{+}1.0963440 \times 55{=}\ 129.4652$$

and similarly,

$$p_{f2} = 22.2816575{+}1.5187061 \times 17{+}0.5503503 \times 25{+}1.0963440 \times 48{=}114.4829.$$

The second and third columns are providing the lower and upper limits of prediction interval. For example, **lwr** $=$ **125.9713** is the lower limit of prediction interval obtained from $\left(p_f - t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2[1 + x_0^T(X^TX)^{-1}x_0]}\right)$ and **upr** $=$ **132.9591** indicates the upper limit of prediction interval obtained from $\left(p_f + t_{\frac{\alpha}{2},n-k-1}\sqrt{\hat{\sigma}^2[1 + x_0^T(X^TX)^{-1}x_0]}\right)$. This suggests that the predicted value lies in the interval (125.9713, 132.9591) with 95% chance. Similarly, the second predicted value for which **lwr** $=$ **111.0423** and **upr** $=$ **117.9236** lies in the interval (111.0423, 117.9236) with 95% chance.

4 Large Number of Explanatory Variables

It is not a debatable issue that large number of factors and variables affect the outcome of any process and suppose that we decide to consider all possible factors and variables. In such a case, use of a large number of variables triggers its own issues, e.g., the explanatory power of the variables is distributed among large number of variables, and so it becomes challenging to identify, which are the crucial variables in the sense that they contribute more in understanding the model. Sometimes it is challenging to perform the computations due to large number of variables, e.g., inverting the matrix of high order may be difficult, etc. Out of these large numbers of variables, the question is how to choose those variables, which are more crucial and contribute more in explaining the model. This objective can be achieved by observing the values of regression coefficients (β_j's). If value of any regression coefficient is minimal, ideally $\beta_j = 0$, then this means that the rate of change in the average value of study variable with respect to a unit change in the value of associated jth explanatory variable X_j is minimal. This indicates that X_j is not contributing significantly in explaining the behaviour of the model. Hence it is not a relevant variable and can be dropped from the model.

It is assumed that all the explanatory variables are independent of each other and correlation between any two variables is ideally zero. This is usually not possible in practice to achieve and the presence of such correlation increases the variability of estimates of regression coefficient. Consequently, the model becomes undependable. This is termed as problem of multicollinearity. One popular approach to estimate the parameters under the problem of multicollinearity is ridge regression introduced by Hoerl and Kennard (1970). The idea behind the ridge regression is to impose a penalty on the regression coefficient and then estimate them. This will help in choosing those regression coefficients, which are away from zero and thus assisting the modelling in two ways- obtaining the estimates of regression coefficients and choosing the irrelevant variables. This concept was extended by Tibshirani (1996) in introducing the LASSO (least absolute shrinkage and selection operator) regression to choose those explanatory variables whose corresponding regression coefficients are away from zero. Needless to mention that the LASSO is computational and algorithm-based technique. Various versions, extensions, developments and improvements in LASSO have been developed. In a general framework, such regression is called as regularized regression. Now we give a brief application-oriented exposition of such techniques. Our objective is to introduce LASSO but a brief introduction to ridge regression is required to understand the philosophy of LASSO.

5 Ridge Regression Modelling

As mentioned in Sect. 2, we very often face a challenge of having large number of explanatory variables in practice. However, many of them may not be impactful on the response variable. To overcome this problem in practice, one may choose only the significant explanatory variables and conduct the analysis based only on those covariates. In literature, various regularized regression methodologies have been proposed to solve this problem, and one such popular form of regularized regression is ridge regression. Ridge regression is motivated by a limited problem of minimization (constrained), which places a constraint on the sum of squares of the coefficient's weights and can be formulated as follows:

$$\hat{\beta}_{ridge} = \arg \min_{\beta \in \mathbb{R}^k} \sum_{i=1}^{n} (Y_i - X_i^T \beta)^2 \tag{24}$$

subject to $\sum_{j=1}^{k} \beta_j^2 \leq t^*$ for $t^* \geq 0$. The feasible set for this minimization problem is therefore constrained to be $S(t^*) = \{\beta \in \mathbb{R}^k : ||\beta|| \leq t^*\}$, where $\beta = (\beta_1, \beta_2, \ldots, \beta_k)^T$ does not include the intercept β_0. Note that the L_2-penalty refers to the constraints $\sum_{j=1}^{k} \beta_j^2 \leq t^*$, which mean that the coefficients are not estimated freely but the estimated values have to satisfy the condition $\sum_{j=1}^{k} \beta_j^2 \leq t^*$, where t^* is a given value. Note that the subscript 2 in L_2 corresponds to superscript 2 (or square) in β_j^2. The ridge estimators are not equivariant under a re-scaling of the x_j's, because of the L_2-penalty. This issue is overcome by centering the explanatory variables. Using a Lagrange multiplier technique for constrained optimization, this problem of finding out the value of regression coefficients β under the constraints $\sum_{j=1}^{k} \beta_j^2 \leq t^*$ can be alternatively formulated as

$$\hat{\beta}_{ridge} = \arg \min_{\beta \in \mathbb{R}^k} \left\{ \sum_{i=1}^{n} (Y_i - X_i^T \beta)^2 + \lambda \sum_{j=1}^{k} \beta_j^2 \right\}. \tag{25}$$

In fact, the residual sum of squares (i.e., like SS_{reg} in multiple linear regression) in ridge regression can be expressed as

$$RSS(\beta, \lambda) = (y - X\beta)^T (y - X\beta) + \lambda\beta^T \beta\,.$$

One can minimize $RSS(\beta, \lambda)$ using straightforward applications of matrix calculus. In other words, the ridge regression estimator satisfies the following equation:

$$\frac{\partial}{\partial\beta} RSS(\beta, \lambda) = 0 \Leftrightarrow 2(X^T X)\beta - 2X^T y + 2\lambda\beta = 0.$$

Solving this equation, we get the ridge regression estimator of β as follows:

$$\hat{\beta}_{ridge} = (X^T X + \lambda I)^{-1} X^T y, \tag{26}$$

where I is an $k \times k$ identity matrix. It may be noted that when the variables $X_1, X_2, \ldots, X_k$ are correlated then $X^T X$ becomes singular. Consequently, $(X^T X)^{-1}$ is not obtainable, and hence the OLSE $\hat{\beta} = (X^T X)^{-1} X^T y$ cannot be obtained. When the value λ is added in the diagonal elements of $X^T X$, then its non-singularity is disturbed, and ridge regression estimator in (26) can be obtained. Moreover, as $\lambda \to 0$, $\hat{\beta}_{ridge} \to \hat{\beta}$ and as $\lambda \to \infty$, $\hat{\beta}_{ridge} \to 0$.

Recall that $\hat{\beta}$ denotes the ordinary least squares estimator of β and (26) can be expressed

$$\hat{\beta}_{ridge} = [I + \lambda(X^T X)^{-1}]^{-1} \hat{\beta}, \tag{27}$$

and in particular, when X is an orthonormal matrix (i.e., $X^T X = X X^T = I$), we have

$$\hat{\beta}_{ridge} = \frac{1}{1 + \lambda} \hat{\beta}. \tag{28}$$

Equation (28) indicates that the ridge estimator is simply a down-weighted version of the ordinary least squares estimator. In other words, in case $\hat{\beta}$ is insignificant, then corresponding ridge estimator will make it significantly smaller than the original ordinary least squares estimator.

An issue in obtaining the ridge regression estimator is how to choose the value of λ. A popular technique is to use the ridge trace. Since our objective in this article is to demonstrate how to choose the subset of relevant explanatory variables, so instead of going into the details of ridge regression, we illustrate how the concept of ridge regression helps in obtaining LASSO in the next section.

6 LASSO Regression Modelling

Lasso regression is more helpful in selecting a subset of "important" explanatory variables from a pool of all the explanatory variables under consideration. This is also referred to as "subset selection". The ridge regression essentially re-scales the ordinary least squares estimates. The LASSO, in contrast, tries to produce a sparse solution, in the sense that several of the regression coefficients will be set to zero. The meaning of sparse in this context is that when most of the elements are zero, then it is termed as sparse. Ridge regression also tries to find the variables, whose regression coefficients are nearly zero. One may therefore refer to ridge regression as soft threshold, whereas the subset selection is a hard threshold; since, in the latter, only a subset of the explanatory variables are included in the final model. The LASSO minimization problem can be formulated as

$$\hat{\beta}_{ridge} = \arg\min_{\beta \in \mathbb{R}^k} \sum_{i=1}^{n} (Y_i - X_i^T \beta)^2 \tag{29}$$

subject to $\sum_{j=1}^{k} |\beta_j| \leq t^*$ for $t^* \geq 0$. The interpretation of this constraint is similar to the constraint in ridge regression with a difference that now the sum of absolute values of regression coefficients is considered whereas earlier the sum of squared values of regression coefficient was considered.

This can again be re-formulated using the Lagrangian function for the L_1-penalty as follows:

$$\hat{\beta}_{lasso} = \arg\min_{\beta \in \mathbb{R}^k} \left\{ \sum_{i=1}^{n} (Y_i - X_i^T \beta)^2 + \lambda \sum_{j=1}^{k} |\beta_j| \right\},$$

where $\lambda \geq 0$, and as before, there exists a one-to-one correspondence between t^* and λ. Note that the subscript "1" in L_1 refers to the power of β_j, which is here 1. Also, in case of ridge regression, a closed-form solution was obtained, see, e.g., (27) or (28). Contrary to the ridge regression, the LASSO does not admit a closed-form solution. The L_1-penalty makes the solution of (29) non-linear in the y_i's. This type of constrained minimization is a quadratic programming problem, whose solution can be efficiently approximated.

6.1 Selecting the λ Value for Ridge and LASSO

The process of choosing $\lambda \geq 0$ primarily depends upon the constraint $\sum_{j=1}^{k} |\beta_j| \leq t^*$. The choice of t^* plays a crucial role in selecting the subset of explanatory variables. Larger value of t^* will select those variables, which are away from zero. Too small values of λ can lead to overfitting when the model would tend to describe the random errors or noise in the data. On the contrary, too large values of λ would lead to under fitting when the procedure cannot capture the underlying relationship. In both cases, we will get a high error value when calculated on the test data.

Cross-validation is one of the most powerful techniques that can be used to find a "most suitable" value for the λ for a given data. By "most suitable" here we mean that we are trying to find λ that would allow us to predict the values of study variable with the highest accuracy.

To perform the cross-validation, the initial data is divided into two subsets: one is called the training set and the other one is called the test set. The training set then is used to calculate the coefficient estimates. These estimates are then validated on the test set. Let us now describe the algorithm in some more detail. At first, the initial data set is randomly divided into B blocks of equal length. One of the blocks is assigned the role of the test set while the remaining $(B-1)$ blocks together constitute the training set. In practice, the number of blocks B is usually selected to be 5 or 10. Next, we choose a grid of values $\lambda = \lambda_s$ and calculate the regression coefficients for each λ_s value. Given these regression coefficients, we then compute the residual sum of squares:

$$RSS_{\lambda_s,k} = \sum_{i=1}^{n} \left(y_i - \sum_{j=1}^{k} \hat{\beta}(k, \lambda_s) x_{ij} \right), \tag{30}$$

where $k = 1, 2, \ldots, B$ is the index of the block selected as the test set. One can obtain the average of these RSS values over all blocks as follows:

$$MSE_{\lambda_s} = \frac{1}{B} \sum_{k=1}^{B} RSS_{\lambda_s,k}. \tag{31}$$

Finally, λ is then set equal to λ_s that gives the minimum MSE_{λ_s}.

6.2 *Implementation of Ridge Regression and LASSO Using R*

To compute the coefficient vectors β using the technique of ridge regression and LASSO, one can use *R* software.

Example (contd.): We consider the earlier Example in Sect. 3, where the rainfall during the monsoon season was assumed to depend on three variables viz., wind speed, precipitation and relative humidity. Now three more variables, which we expect that they affect the rainfall are added. The new variables are number of cars per square kilometer in a city, population density (number of persons per square kilometer) in a city and aluminum toxicity in soil (in ppm $\times 10^{-2}$) and the full data is given in Table 2. Note that the data on earlier variables, viz., y, x_{1i}, x_{2i} and x_{3i} remains unchanged.

Table 2 Data on rainfall, wind speed, precipitation, relative humidity, number of cars per square kilometer, population density and aluminum toxicity in soil

Observation number (i)	Rainfall (y_i)	Wind speed (x_{1i})	Precipitation (x_{2i})	Relative humidity (x_{3i})	Number of cars (x_{4i})	Population density (x_{5i})	Aluminum toxicity (x_{6i})
1	122.0	18.3	29.1	52.0	288	387	356.0
2	114.6	15.7	23.5	50.8	259	131	263.0
3	135.4	15.7	29.8	65.2	259	439	985
4	136.1	19.5	25.5	64.0	291	733	655
5	135.7	15.4	25.7	68.7	725	434	765
6	119.1	19.7	20.2	50.2	429	826	763
7	128.1	19.2	26.4	57.5	729	335	734
8	126.1	15.1	20.6	64.3	825	927	574
9	125.2	19.6	24.2	53.5	229	732	783
10	137.4	18.2	26.5	67.2	628	350	935

We want to employ the ridge regression estimation and variable selection using LASSO on this data set.

The data on additional variables number of cars per square kilometer, population density and aluminum toxicity in soil are denoted as **cars**, **popden** and **alutox**, respectively. The data is entered in *R* software using the following commands:

```
car=c(288, 259, 259, 291, 725, 429, 729, 825, 229, 628)
popden=c(387, 131, 439, 733, 434, 826, 335, 927, 732,
350)
alutox=c(356, 263, 985, 655, 765, 763, 734, 574, 783,
935)
```

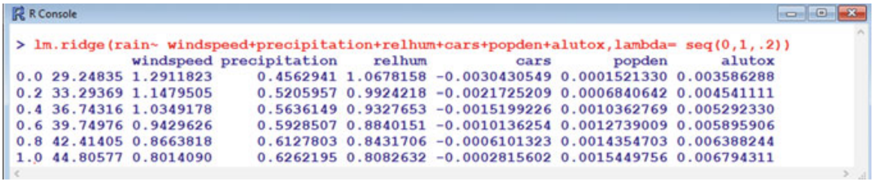
Ridge regression:
We need a library MASS in the *R* software, which can be loaded by using the command **library(MASS)**. We choose the values of λ as 0, 0.2, 0.4, 0.6, 0.8, 1.0 for illustration, which can be generated by the *R* command **seq (0, 1, 0.2)** and then the *R* command **lm.ridge()** can be used to fit a ridge regression as follows:

```
lm.ridge(rain ~ windspeed + precipitation + relhum +
cars + popden + alutox, lambda = seq(0, 1, 0.2))
```

This command computes $\hat{\beta}_{ridge} = (X^T X + \lambda I)^{-1} X^T y$ for the given values of λ = **seq(0, 1, 0.2)** = (0.0, 0.2, 0.4, 0.6, 0.8, 1.0). The values of λ are mentioned in the first column in the given outcome as follows:

```
> lm.ridge(rain~
windspeed+precipitation+relhum+cars+popden+alutox,lambda=
seq(0,1,.2))

            windspeed precipitation    relhum          cars       popden      alutox
0.0 29.24835 1.2911823     0.4562941 1.0678158 -0.0030430549 0.0001521330 0.003586288
0.2 33.29369 1.1479505     0.5205957 0.9924218 -0.0021725209 0.0006840642 0.004541111
0.4 36.74316 1.0349178     0.5636149 0.9327653 -0.0015199226 0.0010362769 0.005292330
0.6 39.74976 0.9429626     0.5928507 0.8840151 -0.0010136254 0.0012739009 0.005895906
0.8 42.41405 0.8663818     0.6127803 0.8431706 -0.0006101323 0.0014354703 0.006388244
1.0 44.80577 0.8014090     0.6262195 0.8082632 -0.0002815602 0.0015449756 0.006794311
```

The screenshot of this outcome, when executed over the R software, is as follows:



```
R Console
> lm.ridge(rain~ windspeed+precipitation+relhum+cars+popden+alutox,lambda= seq(0,1,.2))
            windspeed precipitation    relhum          cars       popden      alutox
0.0 29.24835 1.2911823     0.4562941 1.0678158 -0.0030430549 0.0001521330 0.003586288
0.2 33.29369 1.1479505     0.5205957 0.9924218 -0.0021725209 0.0006840642 0.004541111
0.4 36.74316 1.0349178     0.5636149 0.9327653 -0.0015199226 0.0010362769 0.005292330
0.6 39.74976 0.9429626     0.5928507 0.8840151 -0.0010136254 0.0012739009 0.005895906
0.8 42.41405 0.8663818     0.6127803 0.8431706 -0.0006101323 0.0014354703 0.006388244
1.0 44.80577 0.8014090     0.6262195 0.8082632 -0.0002815602 0.0015449756 0.006794311
```

Every row in this outcome corresponds to the values of $\hat{\beta}_{ridge}$ for a given value of λ. For example, first row gives $\hat{\beta}_{ridge} = (29.24835, 1.2911823, 0.4562941, 1.0678158, -0.0030430549, 0.0001521330, 0.003586288)^T$ corresponding to $\lambda = 0$ giving the model $rain = 29.24835 + 1.2911823 * windspeed + 0.4562941 * precipitation + 1.0678158 * relhum - 0.0030430549 * cars + 0.0001521330 * popden + 0.003586288 * alutox$.

Similarly, second row in the output gives $\hat{\beta}_{ridge} = (33.29369, 1.1479505, 0.5205957, 0.9924218, -0.0021725209, 0.0006840642, 0.004541111)^T$ corresponding to $\lambda = 1$ giving the model $rain = 33.29369 + 1.1479505 * windspeed + 0.5205957 * precipitation + 0.9924218 * relhum - 0.0021725209 * cars + 0.0006840642 * popden + 0.004541111 * alutox$.

Lasso:

Next, we conduct the subset selection of explanatory variables using the *R* software and we aim to find out the explanatory variables corresponding to whom the regression coefficient is close to zero. For this, we need a package **`iilasso`**, which can be installed using the *R* command **`install.packages("iilasso")`**. Then the command **`lasso()`** is used as follows:

```
> lasso(X, y, family = "gaussian", impl = "cpp",
lambda.min.ratio = 1e-04, nlambda = 5, lambda = NULL,
warm = "lambda")
```

The explanation of different quantities in the argument is as follows:

`X` represents matrix of observations on explanatory variables, **`y`** represents vector of observations on study variable, **`family`** represents the family of regression, which is "**Gaussian**" by default, **impl** represents implementation language of optimization, which is "**cpp**" by default, **lambda.min.ratio** represents the ratio of maximum and minimum values of lambda (and ignored if **lambda** is specified), **nlambda** represents the number of lambda values (and is ignored if lambda is specified), **lambda** represents the sequence of lambda, **warm** represents the start direction, which is "**lambda**" (by default).

Smaller value of **lambda.min.ratio** will make most of the irrelevant regression coefficients to be zero at a faster rate. A good value is chosen by carrying out the analysis with various choices of λ. The choice of experimenter governs the choice of number of λ (denoted by **nlambda**).

In this case, **X** and **y** are obtained using the following *R* commands:

```
X=matrix(10, 6, data = c(windspeed, precipitation,
relhum, cars, popden, alutox))
y=matrix(10, 1, data=c(rain))
```

The outcome of the LASSO command is as follows:

```
> lasso(X, y, family = "gaussian", impl = "cpp", lambda.min.ratio =
1e-04, nlambda = 5, lambda = NULL, warm = "lambda")

$beta_standard
     [,1]     [,2]       [,3]        [,4]        [,5]
[1,]    0 1.093604  2.2540010  2.36140700  2.37006178
[2,]    0 1.211091  1.3580289  1.36199061  1.36741534
[3,]    0 5.645381  7.1753399  7.36416278  7.37978940
[4,]    0 0.000000 -0.5473151 -0.66697505 -0.67714038
[5,]    0 0.000000  0.0000000  0.02745814  0.03623476
[6,]    0 1.172396  0.8320210  0.78825473  0.78336277

$lambda
[1] 6.8514073913 0.6851407391 0.0685140739 0.0068514074 0.0006851407

$alpha
[1] 1

$delta
[1] 0

$beta
     6.85140739126796 0.685140739126797 0.0685140739126797 0.00685140739126797 0.000685140739126797
[1,]                0       0.595512226        1.227395626        1.2858825615         1.2905954387
[2,]                0       0.403999981        0.453016174        0.4543377503         0.4561473537
[3,]                0       0.816642613        1.037961474        1.0652759794         1.0675364769
[4,]                0       0.000000000       -0.002455242       -0.0029920340        -0.0030376354
[5,]                0       0.000000000        0.000000000        0.0001125857         0.0001485722
[6,]                0       0.005371423        0.003811968        0.0036114497         0.0035890369

$a0
       [,1]     [,2]     [,3]     [,4]     [,5]
[1,] 127.97 55.18544 31.88029 29.52176 29.27646
attr(,"names")
[1] "6.85140739126796"     "0.685140739126797"    "0.0685140739126797"   "0.00685140739126797"
"0.000685140739126797"

$family
[1] "gaussian"
```

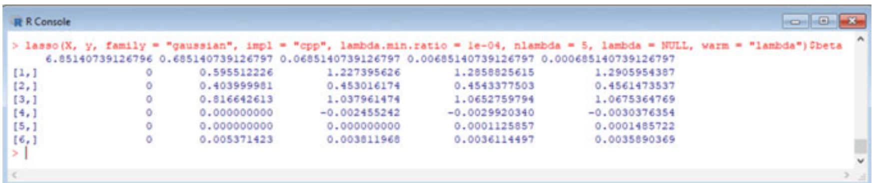
The screenshot of this outcome when executed over the *R* software is as follows:

```
R Console
> lasso(X, y, family = "gaussian", impl = "cpp", lambda.min.ratio = 1e-04, nlambda = 5, lambda = NULL, warm = "lambda")
$beta_standard
     [,1]     [,2]       [,3]        [,4]        [,5]
[1,]    0 1.093604  2.2540010  2.36140700  2.37006178
[2,]    0 1.211091  1.3580289  1.36199061  1.36741534
[3,]    0 5.645381  7.1753399  7.36416278  7.37978940
[4,]    0 0.000000 -0.5473151 -0.66697505 -0.67714038
[5,]    0 0.000000  0.0000000  0.02745814  0.03623476
[6,]    0 1.172396  0.8320210  0.78825473  0.78336277

$lambda
[1] 6.8514073913 0.6851407391 0.0685140739 0.0068514074 0.0006851407

$alpha
[1] 1

$delta
[1] 0

$beta
     6.85140739126796 0.685140739126797 0.0685140739126797 0.00685140739126797 0.000685140739126797
[1,]                0       0.595512226        1.227395626        1.2858825615         1.2905954387
[2,]                0       0.403999981        0.453016174        0.4543377503         0.4561473537
[3,]                0       0.816642613        1.037961474        1.0652759794         1.0675364769
[4,]                0       0.000000000       -0.002455242       -0.0029920340        -0.0030376354
[5,]                0       0.000000000        0.000000000        0.0001125857         0.0001485722
[6,]                0       0.005371423        0.003811968        0.0036114497         0.0035890369

$a0
       [,1]     [,2]     [,3]     [,4]     [,5]
[1,] 127.97 55.18544 31.88029 29.52176 29.27646
attr(,"names")
[1] "6.85140739126796"     "0.685140739126797"    "0.0685140739126797"    "0.00685140739126797"    "0.000685140739126797"

$family
[1] "gaussian"
```

In practice, an experimenter would be more interested in finding out the value of $\hat{\beta}_{lasso}$ and hence we extract the values of $\hat{\beta}_{lasso}$ by adding **`$beta`** in the **`lasso()`** command as follows with following outcome:

```
> lasso(X, y, family = "gaussian", impl = "cpp", lambda.min.ratio =
1e-04, nlambda = 5, lambda = NULL, warm = "lambda")$beta
6.85140739126796 0.685140739126797 0.0685140739126797 0.00685140739126797 0.000685140739126797
[1,]                0       0.595512226        1.227395626        1.2858825615        1.2905954387
[2,]                0       0.403999981        0.453016174        0.4543377503        0.4561473537
[3,]                0       0.816642613        1.037961474        1.0652759794        1.0675364769
[4,]                0       0.000000000       -0.002455242       -0.0029920340       -0.0030376354
[5,]                0       0.000000000        0.000000000        0.0001125857        0.0001485722
[6,]                0       0.005371423        0.003811968        0.0036114497        0.0035890369
```

The screenshot of this outcome, when executed over the R software, is as follows:



```
R Console
> lasso(X, y, family = "gaussian", impl = "cpp", lambda.min.ratio = 1e-04, nlambda = 5, lambda = NULL, warm = "lambda")$beta
     6.85140739126796 0.685140739126797 0.0685140739126797 0.00685140739126797 0.000685140739126797
[1,]                0       0.595512226        1.227395626        1.2858825615         1.2905954387
[2,]                0       0.403999981        0.453016174        0.4543377503         0.4561473537
[3,]                0       0.816642613        1.037961474        1.0652759794         1.0675364769
[4,]                0       0.000000000       -0.002455242       -0.0029920340        -0.0030376354
[5,]                0       0.000000000        0.000000000        0.0001125857         0.0001485722
[6,]                0       0.005371423        0.003811968        0.0036114497         0.0035890369
> |
```

The next question is how to draw conclusions and make a decision from this outcome. The rule is to look for those values in the columns, which are close to zero. The variables corresponding to these zero values are ignored, and variables corresponding to non-zero values are retained. The first row gives five values of λ corresponding to **`nlambda`** $=$ **`5`** as follows: **`6.85140739126796, 0.685140739126797,`**

0.0685140739126797, 0.00685140739126797, 0.000685140739126797. The values under each value of λ provides the values of six regression coefficients obtained for $\hat{\beta}_{lasso}$. For example, the values in the second columns indicate $\hat{\beta}_{lasso} = (\hat{\beta}_{1lasso}, \hat{\beta}_{2lasso}, \hat{\beta}_{3lasso}, \hat{\beta}_{4lasso}, \hat{\beta}_{5lasso}, \hat{\beta}_{6lasso})^T$ = (0.595512226, 0.403999981, 0.816642613, 0.000000000, 0.000000000, 0.005371423)^T corresponding to $\lambda = 0.685140739126797$. For this particular set of values, we observe that the last three values (viz., $\hat{\beta}_{4lasso} = 0.000000000$, $\hat{\beta}_{5lasso} = 0.000000000$ and $\hat{\beta}_{6lasso} = 0.005371423$) are very close to zero. Hence one can decide to ignore the corresponding variables X_4, X_5 and X_6. So one can conclude that the variables—number of cars per square kilometer in a city, population density (number of persons per square kilometer) in a city and aluminum toxicity in soil are not making any significant impact on rainfall, and hence, can be dropped from the model. The remaining variables, viz., wind speed, precipitation, and relative humidity are important variables, and thus the model obtained by considering the observations on these three variables will give a good fitted linear regression model based on LASSO selection. The decision to choose the variables in other columns of the outcome, or equivalently using other values of λ is the choice of the experimenter. Usually, any choice will give a similar conclusion with a minor change in the subset of selected explanatory variables. For example, instead of basing the decision on the second column of the output, if third, fourth or fifth columns corresponding to other values of λ are chosen, one can observe that they are also giving a similar indication, i.e., to ignore the three variables, viz., number of cars per square kilometer in a city, population density (number of persons per square kilometer) in a city and aluminum toxicity in soil.

7 Conclusions

We have considered the multiple linear regression modelling and LASSO technique for subset selection of important explanatory variables. These are the useful techniques in finding out a statistical model based on a given set of data on independent and dependent variables. We have given step by step details about how to obtain the model under usual conditions. When any of the assumptions of linear regression model, e.g., constant variance, uncorrelated random errors, correlated explanatory variables, normal distribution of random errors, etc. are violated, then different types of problems occurs and are tackled in different ways. Such methods to find models under these issues have not been discussed in this article. Here it is noteworthy to mention that various types of graphical and analytical procedures are available to test the validity of such assumptions based on the given sample of data. LASSO has also been extended in different directions and various versions and extensions of LASSO like elastic net, group LASSO, sparse group LASSO, overlap group LASSO and fused LASSO are also now available in the literature and software.

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Climate Change and Adaptation Strategies in the Gir Kesar Mango Region of Gujarat

N. Lalitha

Abstract This study focuses on climate change issues in mango cultivation among the Gir Kesar mango producers in Gujarat. The Gir Kesar region that consists of Junagadh and Gir Somnath districts, has been experiencing production losses in the recent past due to changes in climatic factors like rise in temperatures, prolonged winter and unseasonal rains. These changes have also resulted in increased pest attack and poor quality mangoes. The net income realised by farmers in mango farming is quiet low. Lack of awareness of proper pesticide use leads to farmers using harmful pesticides. Some of the climate change adaptation strategies suggested by the agricultural scientists include adopting (a) drip irrigation methods, (b) high density plantation (HDP) and (c) shelter belts. Drip irrigation method would restrict the excessive ground water extraction and in the years of reduced rainfall would also check the salinity ingress.

Keywords Kesar mango · climate change · pests · high density plantation · adoption strategies

1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), climate change affects crop production in several regions of the world, with more negative effects than positive, and developing countries are more vulnerable to such negative impacts (Lipper et al. 2014). India with its larger dependency on agriculture is not an exception to this impending scenario. As climate change related issues are here to stay, we need to look for climate smart agriculture (CSA). CSA addresses three interconnected challenges: raising productivity and incomes, adapting to climate

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change and contributing to climate change mitigation.[1] However, CSA involves adoption of technological solutions and requires continuous extension services to the farmers. The fundamental aspect of CSA is that it promotes coordinated actions by different stake holders including farmers, researchers, private sector, civil society and policymakers to identify climate-resilient pathways through four main action areas: (1) building evidence; (2) increasing local institutional effectiveness; (3) fostering coherence between climate and agricultural policies; and (4) linking climate and agricultural financing (Lipper et al. 2014).

In India, though agriculture is a major economic activity for a sizeable population, its dwindling share in the gross domestic product of the country is a concern for the policy makers. According to the consumption expenditure data of NSSO, 22.5% of the farm households at all India level have income below the poverty line. The low and fluctuating farmer income causes distress for farmers and force farmers to leave farming which will have serious impact on the future of agriculture in the country (Chand 2017). The reasons for such fluctuating farm income ranges from climate induced factors to anthropogenic activities. Government of India has set a goal to double the farmers' income by 2022–23 and has proposed a variety of strategies within and outside the agriculture sector. Of the strategies discussed within agriculture, include diversification towards high value crops (HVC that includes fruits and vegetables) and to increase the area under HVC by 5% every year (Chand 2017).

This paper focuses on the horticulture sector, which is a high value segment and contributes to nearly 30% of the total agriculture output within agriculture sector but is highly vulnerable to climatic changes. India is the second largest producer of fruits and vegetables after China and ranks number 1 in the production of banana, mango, lime and papaya. Rightly so, the Government of India has recommended shifting to the high value crops as one of the strategies for doubling farmers income. Diversification towards HVCs is a viable strategy as the demand for nutritive and quality products has been increasing due to rising per capita income and changes in life styles and preferences for specific type of products (such as organic, fair trade, artisanal) among certain sections in the country. The Income elasticity is positive and is high for fruits, vegetables, pulses and livestock products (Acharya 2015). Further, compared to the 77% gross cropped area (GCA) occupied by the staple crops such as cereals, oilseeds and pulses but which contributed 41% of the total output, HVCs occupied 19% of the GCA and contributed almost the same to the total output (Chand 2017). Though HVCs have high growth potential, the returns are subject to changing climate scenarios, require more capital, modern information communication technologies, quality inputs, and timely information and extension services. This paper looks at the climate change issues pertaining to mango cultivation, particularly with reference to the kesar mango cultivation in Gujarat and the possible adaption of climate smart agriculture/*horticulture* (*emphasis added by us*) by the farmers taking the case of kesar mango cultivators in Gujarat. In doing so, the paper is restricted to the

[1]Nagaich Ranveer. https://www.orfonline.org/expert-speak/climate-smart-agriculture-how-can-we-be-smart-about-it-49648/ accessed on April, 8, 2019.

discussion on the climatic changes observed in the region, the possible adaptation strategies and the current practices that are in vogue.

This paper is organised into six sections. In the second section following this introduction, we provide a highlight of the literature concerning climate change and in the context of climate change issues with reference to mango cultivation. The third section gives an idea about the status of India's mango production in the world, position in exports, and mango production in the state of Gujarat. Section 4 and the sub sections there in provide the impact of climate change in the case of kesar mango cultivation, awareness among farmers about such impacts and adaptation strategies. This section also discusses the adaptation level among the farmers, need for technological inputs and the crop insurance. Section 5 discusses the need for extension services and the last section provides the conclusions.

1.1 Data and Methodology

The paper uses both primary and secondary data. The primary data used in the paper consists of results from a larger survey on Geographical Indications concerning agricultural products supported by the Indian Council of Social Science Research, New Delhi.[2] It also draws from the interviews conducted with the officials of the horticulture department of Government of Gujarat (HDGOG) and scientists with the horticulture department of Junagadh Agricultural University (HDJAU). The paper uses simple descriptive statistics to support the arguments raised in different sections.

2 Climate Change Impact

A few of the climate change impacts observed in different parts of India are: (1) increase in the drought-affected areas and a decrease in precipitation particularly over water stressed dry regions; (2) fewer rainy days with higher intensity of rainfall, leading to flooding, river run off and heavy soil erosion; (3) rising sea levels and coastal erosions with possibility of more areas getting flooded every year, leading to loss of lives, property and agricultural land and other livelihood; (4) increase in the severity of heat waves; (5) emergence of newer pests and diseases than before; (6) fluctuations in the day and night temperature and (7) increase in the salinity ingress particularly in drought affected areas and coastal areas. Salinity reduces agricultural productivity and changes the cropping pattern and salinity also impacts the availability of sweet water for agriculture and drinking purposes. Thus, the direct impact of these would be on the ecosystems, water availability, biodiversity, changing cropping pattern thus affecting the livelihoods and food security. It is cited in Singh

[2]Done collaboratively by Gujarat Institute of Development Research, Ahmedabad and Council for Social Development, Hyderabad.

et al. (2017) that a 2 °C increase in temperature and a 7% increase in precipitation results in a loss of 8.4% of total net-revenue for India. Hence, adaptation to climate variability and change in the system is imperative to sustain the productivity and profitability for the farmers in short to medium run. The socio economic impact of climate change has been crop failure, indebtedness among farmers, reduced quantities of food available for self-consumption and less community and social support system.

Farmers' adaptation to changing climate is constrained by several technological, socio-economic and institutional barriers (Singh et al. 2017). These include limited knowledge on the costs and benefits of adaptation, lack of access to and knowledge of adaptation technologies, lack of financial resources and limited information on changing weather.

The impact of climate change in the horticulture sector include shortened growing period, resulting in reduced production and quality of fruits and vegetables. Major observed effects of climate change on mango include early or delayed flowering, multiple reproductive flushes, transformation of reproductive buds into vegetative ones, variations in fruit maturity and abnormal fruit set (Malhotra 2017). When the reproductive buds turn into vegetative ones, the yield declines. Further increase in temperature during fruit maturity leads to fruit cracking and early ripening of the fruit. Although mango tree is adapted to dry environments experiencing water stress and high evaporative demand, the expected increase of drought and vapour pressure deficit (VPD) would have a negative effect on photosynthesis because of the rapid stomatal closure of the mango tree due to climate change (Normand et al. 2015). Citing several authors Malhotra (2017) in his review observes that in perennial crops like mango, temperature has significant influence on flowering phenology. The percentage of hermaphrodite flowers was greater in late emerging panicles, which coincided with higher temperatures. During peak bloom period, high temperature (35 °C) accompanied by low relative humidity (49%) and long sunshine hours resulted in excessive transpiration and dehydration injury to panicles. Leaf scorching and twig dying are common symptoms of heat stroke in bearing and non-bearing mango plants.

Normand et al. (2015) observe that drought has negative impact on fruit size, the positive impact is on mango fruit quality as drought increases fruit quality by increasing the sugar concentration of the fruit. In their estimate on the possible consequence of climate change on mango production in South Asia, Normand et al. (2015) predict that "the warmer climate during flowering and the warmer and wetter climate during the season of vegetative rest will probably lead to a lower floral induction. On the opposite, the hot and wet climate during fruit growth and vegetative growth will promote good fruit growth and important vegetative growth after harvest. But fruit quality could be reduced and pests and diseases problems could be accentuated."

3 Mango Production Scenario in the World and India

More than 80 countries in the world produce mango. India ranks number one in mango production and has been consistently in the top. However, India's share in total world production has declined from 56% in 1985 to 42% in 2013 (Table 1). For

Table 1 Percentage share of India in total world production of mangoes of select countries

Country	% Share in total world production				
	1985	1991	2000	2010	2013
India	56.4	48.96	42.5	40.37	42.2
China	2.31	6.07	12.99	11.11	10.83
Philippines	2.11	2.69	3.43	2.27	1.95
Kenya	0.2	0.48	0.46	1.59	1.37
Thailand	4.8	5.31	6.57	6.85	7.36
Indonesia	2.5	3.58	3.54	3.46	4.83
Pakistan	4.2	4.34	3.79	4.96	3.89
Mexico	6.7	6.25	6.31	4.39	4.46
Brazil	3.2	3.08	2.18	3.2	2.73
Bangladesh	1	1	0.76	2.82	2.23
World+ (total)	16.5	17.9	24.7	37.2	42.7

Source Kavita (2017), Table 1, p. 20
Note World total is in million tonnes

the same period however, share of China has increased from 2.3 to 10.8%. Table 1 also informs that Kenya and Thailand have been consistently increasing their production performance.

Almost all the countries except Thailand and Peru have experienced a fluctuation in the value realised through export of mangoes (Table 2). Despite being the largest producer, India's presence in the export market is behind Mexico. Percentage share

Table 2 Percentage share of countries in export of mangoes

Country	% Share in world export				
	1985	1991	2000	2010	2013
Mexico	14	46	29	14	18
India	2	8	4	20	12
Thailand	–	1	1	7	11
Brazil	13	2	9	10	9
Peru	0	1	6	8	8
Netherland	4	5	9	14	13
Pakistan	2	2	4	3	3
Ecuador	3	0	2	2	2
Philippines	0	13	10	4	4
Others countries	37	23	24	20	20
World total[a]	64.4	191.7	385.7	1159.8	1689.7

[a]Value in million $
Source Kavita (2017), Table 2, p. 21

of India has declined drastically in 2013 after a steep rise observed in 2010. While it is true that the domestic demand for mango is very high and hence, the quantity available for exports is less, which is perhaps reflected in Table 3. Table 3 also reports that Arab countries have been the major importers of fresh mangoes from India.

3.1 Mango Cultivation in Gujarat

Table 4 informs us that around 25 states of India produce mangoes and Uttar Pradesh, Punjab, Rajasthan, Madhya Pradesh and Haryana are among the states with relatively higher productivity. Uttar Pradesh and Punjab have been in the top position in three consecutive years in mango productivity. Gujarat ranks 5th (2016–17) in mango productivity compared to other states. Interactions with HDGOG and HDJAU revealed that around 20 years back, Gujarat farmers were also cultivating varieties other than Kesar, but in the recent years, only Kesar mango is cultivated. The main reason for the shift is that Kesar mango yields regularly as compared to other popular varieties such as alphonso which bears fruits during alternate years.

Kesar mango is a popular fruit among the consumers in Gujarat. According to the faculty of HDJAU, there are about 15 lakh mango trees in the Gir area alone. The area is increasing by 200–300 ha every year (officials of HDGOG). Total 1.30 lakh hectares is under mango cultivation in Gujarat. Kutch, South Gujarat, Junagadh regions are well known for mango cultivation. Table 5 gives the area and production of mangoes in Gujarat.

The uniqueness of the kesar mango lay in its rich taste, sweetness, saffron colour and fibreless flesh. Gujarat Agro Industries Corporation has registered Gir Kesar mango with the Geographical Indications (GI) registry. Particularly, Junagadh and Gir Somnath districts are the two major production districts of Kesar mango and come in the jurisdiction of the GI area and the mango from this region is known as Gir Kesar mango. In these two districts approximately about 10,000 farmers are engaged in mango cultivation.[3] More than 70% of the farmers are small holders with less than 3 ha of land. Corporate mango farming that involves farming in more than 200 ha is also prevalent and carried out by a handful of big landholders. 3.6% of the estimated 10,000 or 362 farmers have so far registered with Agricultural and Processed Food Products Export Authority (APEDA) for exporting their mangoes. Eight to nine metric tons per annum is the total estimated production in Gujarat. Kesar harvest starts in mid-April and goes on until end of May. Farmers cultivate mango, using saplings that are prepared by either using soft wood graft or approach graft. In the soft wood graft approach, a branch of Kesar mango and a branch of the local variety of mango is used and the resultant plant can be planted after six months. In the approach graft, two plants rub against each other and eventually seal together. This process is done either in a garden or in green house. In the approach grafting, it takes up to 2 years to develop a plant that is ready for sapling. The difference between

[3] According to the horticulture department, Government of Gujarat.

Table 3 Top five countries that import fresh mangoes from India (Quantity in MT, Rs. in crore)

Importing countries	2012–13		2013–14		2014–15		2015–16		2016–17	
	Qty	Rs. crore	Qty	Rs. crore	Qty	Rs. crore	Qty	Rs. crore	Qty	Rs. crore
U Arab Emts	37,599	163	23,047	172	29,232	215	19,974	192	28,483	247
UK	3304	33	3381	45	330	6	1496	32	3031	50
Saudi Arabia	1665	12	1722	12	2171	14	1400	17	2372	24
Qatar	1523	9	770	7	998	8	1016	10	2254	21
Kuwait	828	8	4601	8	787	12	748	13	1100	19
Top 5 total	44,920	225	33,521	245	33,519	256	24,635	264	37,240	362
Other countries	10,665	40	7759	41	9480	47	12,144	57	15,521	82
Total	55,585	265	41,280	285	42,998	303	36,779	321	52,761	444
% share of top 5 countries	81	85	81	86	78	84	67	82	71	82

Source http://agriexchange.apeda.gov.in/IntTrade/TopDestinationAPEDA.aspx accessed on 20th April 2018
Note Figures have been rounded off

Table 4 Major mango producing states in India (Productivity)

S. No.	States	2014–15	2015–16	2016–17 (Provisional)
1	Uttar Pradesh	17	17	17
2	Punjab	17	17	17
3	Rajasthan	14	16	17
4	Madhya Pradesh	15	13	12
5	Haryana	10	10	12
6	Assam	10	10	10
7	Bihar	9	10	10
8	Andhra Pradesh	9	9	10
9	Karnataka	9	10	10
10	Telangana	9	9	9
11	West Bengal	8	7	9
12	Jharkhand	10	8	8
13	Gujarat	8	8	8
14	Tamil Nadu	6	8	7
15	Nagaland	7	7	7
16	Chhattisgarh	6	6	6
17	Kerala	6	5	6
18	Tripura	6	5	5
19	Mizoram	5	5	5
20	Uttarakhand	4	4	4
21	Odisha	4	4	4
22	Maharashtra	5	3	3
23	Jammu & Kashmir	2	2	2
24	Himachal Pradesh	1	1	1
25	Arunachal Pradesh		1	1
	Others	3	4	
	Total	9	8	9

Source Horticultural Statistics at a Glance, 2017, p. 242
Note Productivity in MT/ha

the two is that while it takes 5 years to yield in the sapling obtained through soft wood grafting method, it takes around 4 years to get yield through approach grafting method.

It is evident from Table 5 that all the districts experienced a reduction in the mango yield with a relatively steeper decline in Gir Somnath and Junagadh districts compared to other districts.

Table 5 Mango acreage and production in major districts of Gujarat

District	2017–18		2016–17	
Name	Area (ha)	Production (tonnes)	Area (ha)	Production (tonnes)
Valsad	35,541	242,361	34,624	335,852.8
Navsari	32,665	300,252	32,175	312,097.5
Gir Somnath	14,820	85,215	14,520	133,584
Kutch	10,033	72,739	9815	91,206.5
Junagadh	8565	47,108	8490	78,108
Amreli	6996	60,108	6965	61,918.9
Bhavnagar	6082	50,429	6388	52,701

Source https://www.thehindubusinessline.com/economy/agri-business/kutch-racing-ahead-in-kesar-mango-cultivation/article26536039.ece accessed on April 10, 2019
Note Gir Somnath district has been carved out of Junagadh district

4 Climate Change Issues Concerning Kesar Mango Cultivation and Mitigation Strategies

HDJAU officials noted the heavy disturbance in the climate for the past five years. According to them, normally, the rainy season which starts in June continues till August and mostly ends in August. When the rainfall ends in August, farmers go for intercultural operations to expose the soil and to reduce the water stress for the trees in September. After this, no other operation is done which is called the resting period for the trees. However, in the recent years, the rainfall starts late and continues till September or October. The officials observed in the recent three years, the Kesar mango region had experienced heavy rainfall till mid-October which delays the intercultural operations. As the climate becomes cooler with the onset of November, there is no resting period of the tree. In this climate, the mango hopper, which is a dormant pest, travels through the trunk of the tree and heavy infestation is seen if not checked when the pest is still at the trunk level. As the panicles turn to flowers, farmers start spraying heavy pesticides on the panicles. Flowering also coincides with the powdered mild dew disease. As this is the time pollination takes place (which normally would have been taken care of by the honey bees), the pesticide operation affects the pollination and only a few flowers bear the fruits. The officials also observed that the pesticide spraying also affects the honeybee population in the region. Scientists in JAU have also observed the emergence of a new pest in the recent five years, known as 'Blossom Mindge' which thrives on the new fertilized embryo. Both HDGOG and HDJAU officials observed another impact of climate fluctuation, which is known as fruit drop. Fruit drop or the stenospermo carp is a situation where no pollination takes place and the embryo aborts. This disease loosens the connection between the fruit and the stem, leading to the fruit drop from the tree. This is attributed primarily to climate change. The HDJAU and the HDGOG observed that for healthy flowering to take place, the temperature has to be between

12 and 18 °C during night and the day temperature should not exceed more than 25 °C. If the temperature increases beyond this level, then only vegetation increases and no flowering occurs. The year 2018 had been particularly of a period of brief winter followed by rise in the day temperature. Hence, both the officials and the farmers predicted a reduction in the yield, which became true during the 2018 April–June season[4] as the production dropped by 50%. In 2019, there has already been damage due to the unseasonal rain and storm[5] in February and now in April.[6] The 2019 season witnessed a prolonged winter and double climate. Due to this farmers noted the flowering to continue in February as well, while normally that is the time for raw mangoes to be seen in the trees. As the Gir Somnath region had experienced the climate fury, production is expected to decrease by 50% in the 2019 season. But as against this, Kutch also produces Kesar mango mainly using drip irrigation and hence is racing ahead with more acreage and production.[7] Our interviews with the traders in Talala and Ahmedabad also revealed that Kutch mangoes which arrive later than Gir Kesar mangoes, command a relatively higher price than Kesar mangoes due to their sugar content. It may be noted that Kutch is a highly water deficient district and as noted by Normand et al. (2015) drought reduces fruit size and increases fruit quality by increasing the sugar concentration of the fruit.

A mango crop model to assess more precisely the effects of climate change on mango production, and to propose simulation-based ways for mango cultivation to cope with climate change is not yet in place (Normand et al. 2015). Malhotra (2017) adds that in the horticultural segment crop model is available for potato and coconut only. However, HDJAU officials pointed out a variety of climate change adaptation strategies that could be followed by farmers. One is to create shelterbelts around the mango gardens that will prevent the hot winds affecting the flowers and preventing the fruit drop.[8] HDGOG noted that farmers do not visit their gardens frequently. University scientists noted that as the farmers visit the field very infrequently till December, they notice the heavy infestation of the mango hopper only when the pests have travelled from the trunk to the new green flushes, which bear the panicles that would eventually turn to flowers and fruits. As the farmers panic and spray pesticides, they usually tend to spray more than what is required affecting the pollination and burning of the flowers. Thus, both the climate and anthropogenic factors reduce the yield. When there is prolonged cold weather and dew is formed on the green flush, farmers need to follow the smudging technique, which is burning the farm waste in the garden to create warmth and facilitate fruit setting.

[4]https://timesofindia.indiatimes.com/city/rajkot/kesar-mango-production-likely-to-dip-by-40/articleshow/58322047.cms, on September 20, 2018

[5]https://timesofindia.indiatimes.com/city/rajkot/rain-storm-cause-severe-damage-to-kesar-mango-crop/articleshow/68191959.cms, accessed on April 11, 2019.

[6]https://timesofindia.indiatimes.com/city/surat/unseasonal-rain-lashes-south-gujarat/articleshow/68895896.cms, accessed on April 16, 2019.

[7]https://www.thehindubusinessline.com/economy/agri-business/kutch-racing-ahead-in-kesar-mango-cultivation/article26536039.ece

[8]In Jamnagar, Reliance group which is promoting mango orchards in more than 250 ha of land is following the shelter belt technique.

Scientists also said that as the climate change issue is going to remain with us, new varieties of mango which are tolerant to climate change is required. Now in the mango region of the state, scientists' are actively promoting high density plantation (HDP). HDP is a technology that has been learnt from Israeli scientists. HDP is a method followed in orchards in Israel. Following this, the HDGOG has set up a centre of excellence (CE) in Talala in Gir taluka, where the modern HDP is practiced which is an ideal strategy to combat climate change. The HDGOG tries out new techniques in its own farm in the CE and then trains the farmers. HDP is a technique, which optimizes the area. Compared to the old method of plantation where distance between two trees is more than 10 m, in the HDP the technique adopted is to grow 3 by 3 or 5 by 5 (distance in meter). Farmers will be able to cultivate more than 1000 trees in a hectare by following HDP of 3 by 3. According to the scientists of the university, climate change damages could be arrested to a significant extent by HDP as the plants are close to each other and hence the heat penetration would be less and this is beneficial at the time of flowering and fruit setting. This helps in arresting the fruit drop as well. In HDP canopy management is essential as it helps in better and quality yield. The height of the tree is maintained at around 5 feet with pruning that takes place after harvest every year. Since the tree is short, the fruits can be harvested individually by hand as these are the proverbial 'low lying fruits' and the fruits are of same grade as the bunches are maintained appropriately. Further the chances of fruits getting damaged at the time of harvesting as well as harvesting the fruit which is yet not ready along with the matured fruit is very less.

4.1 Awareness About Climate Change and Adaptation Strategies by Farmers

In this section, we first discuss about the awareness among the farmers about the changes in the climate and its impact as it is essential that the farmers observe the changes that are occurring to their crop and yield.

A primary survey was carried out during May–June 2018 among 171 mango farmers. These farmers were selected based on a list of farmers provided by the HDGOG. Adopting probability proportionate sampling, in Gir Somnath 3 talukas were selected from which 12 villages were identified. In Junagadh 2 talukas and 1 village in each were identified. The selection was based on the number of farmers cultivating mango in each of the talukas and villages. Thus, in Gir Somnath, Talala (9), Una (2) and Veraval (1) talukas and in Junagadh Vanthali (1) and Maliya (1) talukas were selected, and 14 villages therein were selected. Around 12 farmers were randomly selected from each of these villages.

4.1.1 Socio-Economic Profile of the Farmers

Agricultural income is the only major source of livelihood for 65% of the farmers, while 31 and 4% of the farmers had 1 and 2 more sources of income, respectively. Income from agriculture constitutes 84% of Rs. 33,002,020, which is income from all sources. Farmers also realised income from trade and business (4.7%), public services (3.5%), private sector (1.84%), pension (0.06%) and livestock (5%). These 171 farmers were cultivating mango in 353.9 ha, where 80% of the farmers belong to the small holding category with 52% of the total land. Nineteen percent are medium landholders with 44% of the land and one large landholder holds the remaining land. Ninety-nine percent of the area is under traditional type of mango cultivation. In the traditional type of cultivation, the distance between the trees is more than 8 feet. Except for five farmers who have leased in 5.1% (18.45 ha) of the total land under traditional mango cultivation, the rest are all cultivating mango in their own land only. All the farmers had access to water. Fifty-one per cent or 85 farmers have borewell and 145 (86%) have well. Thirty-four per cent had both well and borewell. Only 3% of the total 171 farmers use drip irrigation.

Mango cultivation offers a variety of employment for both male and female workers. Hired labourers are involved in cleaning the garden, creating rings around the trees, irrigation, weeding, application of fertilisers and pesticides, harvesting, sorting and grading, packaging and transporting the produce to the market. All farmers for all the farm operations reported a total labour days of 22,736. Male labourers account for 72% of the total labour days. Male workers are exclusively engaged in pruning, drip irrigation, sprays for pesticide/fungicide, sorting, grading and transportation. Except weeding, which is done exclusively by females, all other jobs are done by male labourers. The wages for the men and women ranged from Rs. 250 to Rs. 400 for different operations.

Taken together, the farmers had realised a total production of 737.4 tonnes of mango in 2017–18, reporting a yield of 2.82 tonne per hectare. This has resulted in a total income of Rs. 28,370,072 or a per hectare gross income of Rs. 83,173.98. The total cost of cultivation in mango farming as reported by the farmers to be Rs. 50,850.52 per hectare, yielding a net income of Rs. 32,323.46 per hectare. Given the fact that these calculations considered only the paid out costs and not imputed the charges for the family labour, it is a precarious situation for the cultivators. In addition, since majority are small farmers, the income from farming has an important role in their livelihoods.

4.1.2 Awareness of the Importance of Climate and Natural Factors

In the horticultural sector in general and in mango cultivation particularly, the climate/natural factors play a crucial role in determining the quantity and the quality of the produce. The Gir Kesar area being near the coastal region, climatic changes have been affecting the yield. While the climatic factors delayed the flowering, fruit bearing nature of the tree and the kind of pests and insects that thrive on these trees,

Table 6 Response of farmers on factors affecting the mango yield

	No. of farmers	% of farmers
No conducive climate	113	66
Adverse insects and fungi attack	67	39
No honey bees	28	16
Very less flowers bore fruits	31	18
Fruit drop	61	36
Unseasonal rain and winds	49	29
Fluctuations in the day and night temperature throughout the fruit bearing season	104	49
Reduced yield	84	49
All of the above	4	2
N	170	

Source GIDR/CSD Survey 2018
Note Due to multiple responses, the *N* and the percentages would not tally to 170 and 100 respectively

human activities also hasten the reduction in yield. Particularly in the context of small land holding, it is important to know the factors and possible mitigation and adaptation strategies. Taken together, 92% of the total farmers believe that climate and natural factors are significantly important for mango cultivation. Of these 78% of the farmers reported drastic changes in the natural factors in the recent years. Ninety-nine per cent of the total respondents also confirmed that these changes are not advantageous for the mango crop.

The earlier section reported the scientists' observations of factors relating to changing climate that affect mango. The sample survey revealed that lack of conducive climate and the fluctuations in the temperature through out fruit bearing season topped the list followed by reduced yield and attack of adverse insects (Table 6).

Majority of the farmers reported reduced yield due to climatic factors. Interestingly as mentioned elsewhere temperature fluctuations also lead to pest attack (Table 7). Hence, the farmers need to buy inputs that are more chemical and engage the labourers to spray the chemicals on the trees. Both these factors rank second and third in the list of impact factors identified by the farmers. Thirty-five farmers had also noted that the fruits dropped before maturity.

4.2 *Climate Change Adaptation Strategies by Farmers*

Researchers suggest a variety of adaptation strategies that include: shifting of the production areas (implications for GI), appropriate root stock selection, improvement in irrigation techniques (Normand et al.), agronomic practices (shorter duration

Table 7 Impacts observed by farmers due to changes in the natural factors

	No. of farmers	% of farmers
Reduced yield	165	97
Size of the fruit was small	17	10
Fruits arrived late in the season	15	9
Fruits dropped before maturity appropriately	35	21
Increased expenditure on pesticides and fungicides	87	51
Increased labour charges to apply pesticides	88	52
Quality not good	27	16
All of the above	3	2
Any other	2	1
N	170	

Source GIDR-CSD Survey, 2018
Note Due to multiple responses, the *N* and the percentage would not tally to 170 and 100 respectively

Table 8 Percentage of farmers by the age of the trees

Age of the tree	% of farmers
Up to 20 years	51[a]
More than 30 years	40
More than 40 years	7.6
More than 50 years	0.6
Total *N*	171

Source GIDR-CSD Survey, 2018
[a]Includes 1 HDP plantation

varieties of crops, mixed cropping strategies), resource conservation technologies (sprinklers and drip irrigation), water management and risk management measures (Singh et al. 2017).

Regarding the shifting of the production areas, as mentioned earlier, Kesar mango is cultivated in a few districts of Gujarat (Table 5). However, only Gir Somnath and Junagadh come under the area of 'Gir Kesar mango' production mentioned in the GI application. Kutch and Valsadi Kesar mangoes are also popular. While newer areas may be brought under mango cultivation, the existing areas would go on because of the place value associated with them. Now we look at the agronomic practices followed by farmers.

As evident from Table 8, a relatively larger percentage of farmers have mango trees that are 20 years of age, which would provide a good yield for another few years. However, these are all under the traditional type of plantations as seen from the distance maintained between the trees except for one progressive farmer (Table 9). This progressive farmer (PF) is practicing HDP for the past 13 years, where 3 m of distance between the trees is maintained. In his 1.21 ha farm, he has 3000 mango trees. This PF works in the mango farm around the year. He uses drip irrigation in

Table 9 Distance between the trees as reported by the farmers

Distance between trees in metres	% of farmers reporting
7	6
8	6
8.5	0.6
9	30
10	33
10.5	0.6
11	10
12	11
13	2.4
18	0.6
N	171

Source GIDR-CSD Survey, 2018

his farm. He maintains the yield level in such a way that he gets around 30 kilograms from a tree. In 2017, he sold 7000 boxes of 10 kg each and his target is to reach 9000 boxes. Once the harvest date is decided, he stops irrigating the trees, which helps in improving the sugar content of the fruits. By maintaining only the healthy fruits and uniform size, he is able to sell uniform "A" grade fruits to his loyal customers in Ahmedabad, Baroda, and Mumbai who book their requirements in advance with him at a price quoted by the farmer. Interestingly, when asked why he is not interested in exports, this farmer said, he does not have adequate yield to cater to his existing customers. He does not advertise or seek new customers.

As evident from the table, very few farmers are aware about the HDP as they have maintained a distance of 7 m (the PF has been included in the frequency of 7 m distance in the table), while 30 and 33% of the farmers have maintained a distance of 9 and 10 m between the trees. When the distance between the trees is relatively high as seen from the table, the branches are spread on their sides and the tree is quiet tall. Experts say that tall trees have more climate change impact than the short trees. When farmers undertake appropriate canopy management, yield commences from the 5th year and the regular income starts after 10th year. However, production stagnates after 15–20 years.

Another strategy suggested to combat climate change is management of water resources. In order to avoid excessive flooding of the mango tree, scientists recommend the use of drip irrigation. HDJAU note that from February to June, five or six irrigation would be required for mango. In the Gir area, 97% of the farmers flood irrigate their garden and a miniscule 3% use drip irrigation. As flood irrigation is the common method of irrigation, over use of resources may not be ruled out. Scientists warn that the moisture content would increase with excessive irrigation, which will attract the pests and diseases, particularly the fruit fly. Drip irrigation, which is one of the strategies to mitigate climate change effect, would be advantageous from the ecology and energy point of view. Drip irrigation, besides providing only the required quantity of water to the trees prevents excessive water extraction from the well/borewell. Overall, there is reduction in the energy use and therefore the expenditure for the farmer would reduce. HDJAU scientists recommend that irrigation should be stopped 20–25 days before harvest. However, when irrigation is continued, the weight of the fruit increases but the sugar content will be relatively less.

Lipper et al. (2014) suggests that CSA emphasizes on agricultural systems that utilize ecosystem services to support productivity, adaptation and mitigation. Examples provided include integrated crop, livestock, aquaculture and agroforestry systems; improved pest, water and nutrient management; landscape approaches; improved grassland and forestry management; and practices such as reduced tillage and use of diverse varieties and breeds to mention a few. However, in the survey, many farmers reported that because of the shade of the mango trees, intercropping is not possible. Fifty per cent of the farmers have livestock and they reported using the livestock manure for mango.

Only 13 farmers use organic practices of which 10 use because they believe that it benefits the soil. Five also believed that organic production has better market. Interaction with farmers and the researchers pointed out however those organic practices are not possible in mango due to the different pests that affect mango cultivation.

Citing literature, Malhotra (2017) recommends rootstalk of 13-1 for Kurakkan, Nileshwar dwarf and Bappakai mango varieties that are salinity tolerant and suitable for saline areas. HDGOG pointed out that no new variety of mango has been brought out in the country that is tolerant to the climatic conditions so far.

4.3 Use of Technological Inputs as an Adaptation Strategy

Farmers until recently depended on their traditional knowledge by observing the movement of insects and ants to predict the likelihood of rainfall (Lobo et al. 2017). These authors observe that the changes in the climate vagaries, loss of resources and livelihood, necessitate that the farmers augment their traditional knowledge based practices with scientific information of weather events through agro-meteorological services. Taking a case of the intervention by an NGO in Maharashtra, these authors explain that the automated weather stations situated in different project villages collect the weather information and send the same to the Indian Meteorological Department (IMD). IMD in turn sends the three-day weather forecasts for the villages covered by the NGO. Besides sending the advisories for immediate action by SMS to the farmers, based on the three-day weather forecasts, the NGO with the help of agri experts prepares weather based crop calendars for different crops in their project villages.

Introduction of ICT based communication among the grape cultivators in Nasik district of Maharashtra has resulted in improving the knowledge of the farmers and preparedness to face the climatic challenges (Lalitha 2018). Here the farmer producer organisation (FPO) has geo tagged all the farms of the member farmers in different

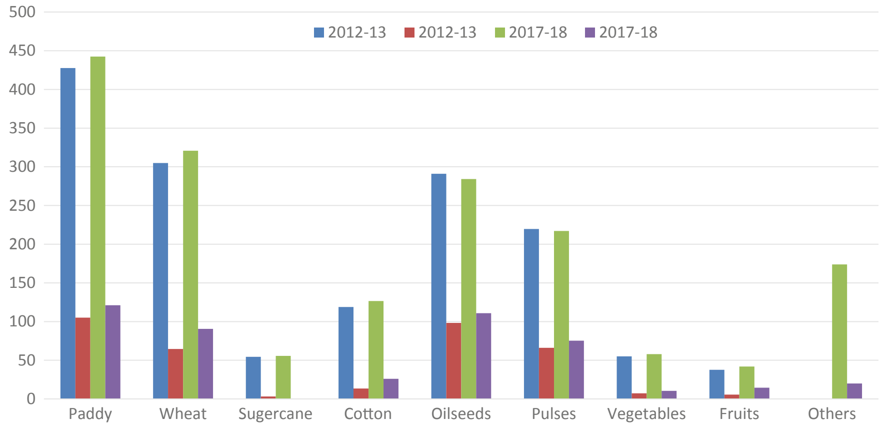

Fig. 1 Gross area shown and area insured (in lakh hectares). *Source* Department of Agriculture, Cooperation & Farmers Welfare (Credit Division). *Gross Area Sown for 2017–18 has been estimated based on the data of 2014–15 (eands.dacnet.nic.in)

villages. Based on the information from the automated weather stations installed in different villages and on the information of the actual plots' soil requirement, appropriate advisories are sent to the farmers through mobile phone services about the possibility of rain/hail storm/heat wave and suggested pesticide or insecticide spray or the need for irrigation.

Impacts of such technological intervention had been improved yield, reduction in cost of cultivation and an increase in the skills, knowledge and preparedness of the farmers.

Crop insurance is another adaptation strategy for the farmers to protect themselves from the vulnerabilities created by the changing climate. Shockingly in our study except for one farmer, the rest do not have any insurance for their crop. It appears that crop insurance is yet to pick up in the context of India. As seen from Fig. 1, compared to the area under cultivation, the area insured is relatively small in all the crops implying that only a few farmers opt for crop insurance. Compared to other crops, in fruits, only a miniscule area is insured. In claiming insurance, automated weather stations would be very helpful. To elaborate, a particular village, which did not get any rain and suffered drying of the crops would find it difficult to get compensation, as the larger weather system would have recorded only widespread rain and not the lack of rain.

5 Need for Extension Services

Lipper et al. (2014) suggest that in order to make climate change adaptation successful, extension and information dissemination particularly to adapt suggested practices according to local conditions is of utmost importance. There are a number of studies on the positive correlation between agricultural extension services (AES) and agricultural productivity. A few studies also discuss the challenges in extending AES that range from inadequate funds to the geographical spread of farmers which affects the reach of extension service and difficulty in maintaining AES staff in faraway places (Sulaiman and Van Den Ban 2003; Ferroni and Zhou 2012; Birkhaeuser et al. 1991).

Until the 1960s, the state Department of Agriculture (DOA) was primarily responsible for agricultural extension services. The agricultural extension service now has a variety of players that includes government (including agricultural universities), private input manufacturers, dealers, civil society organizations, voluntary certification bodies, agencies engaged in export of agricultural products, private value chain actors, farmers' organizations and so on.

In the primary survey, the respondents were asked to provide information on the kind of advice/service/training provided by different institutions such as, university, Krushi Vigyan Kendra, state government, traders, and certification agency, APEDA, ATMA and NGOs.

The results showed that only 17.5% (30 farmers) of 171 had undergone training. Of these 30 farmers, 11 farmers or 36% had undergone training provided by the Junagadh Agricultural University in HDP methods, use of fertiliser and pesticides, pruning and seedling use. A small number of three and four farmers reported receiving training in HDP and value addition methods by traders.

While the limited number of farmers reporting training leaves much to be desired, training in the use of fertiliser and pesticide would lead to reduction in the green gas emissions and help in improving the export quality of the mangoes.

Lalitha and Vinayan (2018) discuss the threat to exports due to high pesticide residue content in mango exports to Europe and United Arab Emirates. UAE tops the list of mango exports from India with more than 70% share in total quantity that is exported (Table 3). The sharp reduction in the export to UAE from 29,232 MT in 2014–15 to 19,974 in 2015–16 reflects the pest issue.[9] In 2014, the EU countries placed a ban on mango exports from India, which resulted in the drastic reduction of quantity from 3381 Mt in 2013–14 to 330 Mt in 2014–15. This ban was withdrawn in 2015 after satisfactory corrective measures were undertaken. Instances of ban by a major importing countries would adversely affect the brand image and export of such products.

[9]http://economictimes.indiatimes.com/news/economy/agriculture/famous-malda-mango-facing-major-export-crisis/articleshow/52418917.cms, accessed on June 23, 2016.

6 Conclusion

Mango is one of the important horticultural crop, highly in demand and has positive export potential. This chapter discussed the climate change issues in the context of Gir Kesar mango in Gujarat alone. Nevertheless, there are several states, which produce mango and perhaps undergoing the impacts of climate change. India is number one in mango production and has considerable export potential. Production loss due to climate change would affect the exports eventually. Recurrent production losses would make the farmers to reduce the area under cultivation or opt for different livelihood.

The brief highlight of the socio-economic analysis showed the precarious situation of the farmers. Hence, any disturbances to yield due to climatic factors would put the farmers in a very vulnerable situation. This study discussed several adaptation measures, though at the ground level such measures have not been adopted at a large scale. This requires considerable extension measures to spread awareness among the farmers. Mitigation measures need to be in place to prevent long-term impact of climate change at the micro and macro level. While at the macro level, countries try to reduce the greenhouse gases through various policy measures, at the micro level coordinated efforts need to continue. For instance, it was mentioned that majority of the farmers are using wells and bore wells to draw water. However, as the rain vagaries are increasing, farmers tend to opt for more ground water extraction. With inadequate rain, the sweet water table would go down and the salinity level would increase, which would affect the quality of the product and eventually the cropping pattern. Hence, it is essential that there is a cap on the ground water extraction in the area. Further, measures like watersheds would improve the ground water table.

The Government of India through the Indian Council of Agricultural Research (ICAR) has launched a scheme My Village My Pride. Under this scheme, ICAR scientists adopt villages from different parts of India to provide technical and other information to farmers. Gir Kesar mango producers who have to deal with the climate change issues would benefit immensely by such guidance.

India is one of the countries that brought out a plan namely National Action Plan on Climate Change (NICC), under which there are various sub-plans for different sectors. One of the focus areas of the national mission for sustainable agriculture is to develop new varieties of crops that are resistant to different challenges in climate. The National Innovations in Climate Resilient Agriculture (NICRA) under Indian Council for Agriculture Research has been focusing on enhancing the resilience of Indian agriculture to climate variability and climate change through strategic research on adaptation and mitigation. Hopefully in future, such efforts would bring out both adaptation and mitigation strategies for the horticulture sector that would help the farmers to realize better returns from horticulture.

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Spatial Shift in Chickpeas in India

B. Abirami and Parmod Kumar

Abstract With increasing malnourishment and being home for a large number of vegetarian populations compared to the rest of the world, India considers Chickpeas as the best alternative for animal proteins. Chickpeas, enriched with high protein content has been gaining importance in the present era as they serve as a supplement for cereal based diets. Climate change as the major challenge faced by other crops, cultivation of chickpeas will become increasingly important in the near future. In the recent times, the traditional chickpeas cultivating area had witnessed reduction in its area and production. At the same time there is an increase in the area under chickpeas cultivation in their unconventional zones of the country. The current study examines the changing patterns in the centre of chickpeas production in India. State wise yearly data on area, production and yield of chickpeas are collected from 1964–65 to 2016–17. The analysis of the data reveals that there is a regional shift in chickpeas cultivation from Northern and Eastern Zones to Southern, Central and Western Zones of the country. The major reason for this regional shift is the changing climate and rainfall pattern and availability of short-duration cultivars in Central and Southern India which are absent in Northern and Eastern Zones.

Keywords Chickpeas · Spatial shift · Protein

1 Introduction

Pulses production in India has witnessed many changes since the advent of Green Revolution. The domination of cereals in Indian agriculture has reduced the importance of cultivation of pulses and their intake. High malnourishment coupled with large vegetarian population, the future of pulses is of special significance in Indian agriculture. India shares 35% of global area and production of pulses (*Directorate of Pulses Development*). India is the largest producer and consumer of pulses (*Food and Agricultural Organisation*). Major pulses grown in India are chickpea, pigeon

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pea, black gram, green gram, lentil and field pea. During 2017–18, cultivated area under pulses was greater than 29 million ha and had the highest production of 25.23 million tonnes with productivity level of 841 kg/ha. Major pulses producing states in India are Madhya Pradesh, Rajasthan, Maharashtra, Uttar Pradesh, Karnataka, Andhra Pradesh, Gujarat, Jharkhand, Tamil Nadu and Chhattisgarh (*Pulses Revolution from Food Security to Nutritional Security, Government of India, 2018*). The highest ever production in 2017–18 was recorded by chickpeas with a production of 11.23 million tonnes at a productivity level of 1063 kg/ha. **Chickpeas (*Cicer arietinum*)** locally known as chana, Bengal gram or gram is the traditional pulse crop grown in South Asia, mainly in India, Pakistan, Iran, Mexico and Ethiopia. Around 95% of the total annual production (8.4 million tonnes) of chickpeas occurs in Asia and Africa (FAOSTAT 2006). The major chickpea producing countries include India (65%), Pakistan (10%), Turkey (7%), Iran (3%), Myanmar (2%), Mexico (1.5%) and Australia (1.5%). It is ranked third in production after peas and dry beans. It is grown as winter crop in tropical regions and summer crop in temperate regions in both rain fed and irrigated conditions. It is grown as rotation crop after cereals like wheat, rice, etc., as they derive 70% of its nitrogen requirement through nitrogen fixation thus enriching the soil fertility.

World's chickpea supply mostly comes from India which contributes about 30% of total pulse acreage for chickpeas cultivation. In developing countries like India, where the poor people are not able to afford animal proteins, chickpea comes in handy as a supplement. There are two major types of chickpeas namely *Desi* and *Kabuli*. Desi types are traditional dark smaller seeds with rougher coat and relatively high yielding and low cost of production and low unit price. Kabuli varieties were introduced during 18th century and they are larger light coloured seeds with smoother coat and relatively low yield (*Pulses.org, 2019*).

Chickpeas cultivation requires fertile sandy, loamy soils as they are neutral to alkaline with a pH ranging from 6.0 to 9.0 and they have very good water holding capacity. Good internal drainage is an essential requirement as excessive water logging even for short periods will result in decreased yield. It requires daytime temperatures of 70–80 °F and night time temperatures of 64–70 °F. Chickpeas consumption by people with diabetes can improve blood sugar levels. High fibre content also improves digestion. The mineral and vitamin contents such as iron, phosphate, calcium, magnesium, manganese, zinc, vitamin-K helps in strengthening the bone structure. The mineral selenium which is not present in fruits and vegetables is found in chickpea which decreases tumour growth rates helping in prevention of cancer. Chickpeas consumption also helps in maintaining blood pressure, heart health, cholesterol, inflammation etc.

Chickpeas play an important role in maintaining soil fertility by fixing up to 141 kg nitrogen per ha. (Rupela 1987). Nitrogen fertilizers are the major reason for the emission of greenhouse gases in the atmosphere. As these crops fix nitrogen by their relationship with bacteria, they either require less nitrogen fertilizers or do not require nitrogen fertilizers at all. Thus, it helps the soil microorganisms to flourish thus improving the soil fertility. This makes the soil fertile and the crop suitable for inter-cropping system. As these crops are primarily rain fed, it also requires less amount of water for its cultivation.

There are various government programmes and policies on the promotion of chickpeas production in the face of changing climate and rainfall pattern. Programmes like Accelerated Pulses Production Programme, National Food Security Mission-Pulses, Rashtriya Krishi Vikas Yojna are being implemented for boosting pulses production in India. The system of Minimum Support Price (MSP) can make cultivation of pulses less risky to farmers. The announced MSPs are less than the market price. Proper procurement and inclusion of chickpeas in Public Distribution can enhance the production of chickpeas. There should be crop insurance schemes and proper infrastructure for safe storage and post-harvest processing.

2 Review of Literature

There are several studies conducted on constraints faced in chickpea production due to adverse weather conditions, changing climate, pest and infestation and their waning profitability. Singh (2018) examined the constraints and shifting of chickpea cultivation in Tal area of Patna district in Bihar. His results identified thirteen different constraints that affects directly or indirectly the cultivation of chickpeas. A few of them are: low market price, low yield, late maturity, high infestation by insects, pests and diseases, socio-economic factor and use of local seeds. Narayan and Kumar (2015) examined the constraints of growth in area, production and productivity of pulses in India. The major constraints included nonavailability of improved technology, High Yielding Variety seeds, lack of fertilizers, marketing facilities, minimum support prices and policy framework to support and encourage farmers to grow pulses.

Usha (2009) in the research study on "Instability in Production and Trade of Pulses" did a global analysis and findings reveal that the potential yield of chickpeas at the world level is 1500–2000 kg/ha but the average yield at the world level was only 770 kg/ha and none of the producing countries achieved the potential yield rate. Reddy and Mishra (2016) studied growth and instability in chickpea production at state level using CAGR, Coefficient of Variation and Coppock's Instability Index. The results reveal that states such as Madhya Pradesh, Maharashtra and Karnataka contributed a positive increase in production while Uttar Pradesh, Punjab and Haryana had a negative contribution.

Maurya and Kumar (2018) analysed growth of chickpea production in India and found that farmers were not very keen on taking up chickpea production because of the high level of fluctuations in production because of various biotic and abiotic factors and the fluctuations in prices because of the absence of an effective government price support mechanism. The study by Gowda et al. (2009) revealed that the major reasons for regional shift were the change in the chickpea profitability in northern states, availability of early maturing varieties in southern and central states and epidemics of blight in north western states.

The study on "Marching towards Self-Sufficiency in Chickpea" by Dixit et al. (2019) states that the required steps to sustain chickpeas production includes assured procurement and inclusion of pulses in the public distribution system, lucrative minimum support price (MSP) in order to make pulses comparable to cereals, buffer stock to meet any contingent condition, strict imposition of holding limit of pulses with traders, extending the benefit of crop insurance schemes to pulses, proper infrastructure for safe storage and post-harvest processing.

3 Research Questions

At present only seven states account for 90% of chickpeas production: Madhya Pradesh (4.60 million tonnes), Maharashtra (1.78 million tonnes), Rajasthan (1.67 million tonnes), Karnataka (0.72 million tonnes), Andhra Pradesh (0.59 million tonnes), Uttar Pradesh (0.58 million tonnes) and Gujarat (0.37 million tonnes) (*Ministry of Agriculture and Farmers' Welfare 2018*). Several studies show that pulses production in India is finding new niche areas where it is reportedly performing better than in the traditional ones (Shiyani et al. 2000; Joshi and Saxena 2002). In the recent years, with special emphasis on chickpeas, all the states have shown an increased per capita consumption but a decreased area under its cultivation. There is a huge gap between demand and supply. The regional movement of centre of chickpeas cultivation is the most important determinant of the gap. This study attempts to fill the following research gaps of the supply side dynamics of chickpeas production in India.

1. Why there is fluctuations in the APY of chickpeas over the past years?
2. Why the trend in chickpeas cultivation changed in Northern, Southern, Eastern, Western and Central Zones of the Country?
3. What are the major reasons for the regional shift in area under chickpeas cultivation?

4 Objectives of the Study

The Objectives of the study includes

1. To examine the trends in Area, Production and Productivity of chickpeas at All India level.
2. To study the trends in Area, Production and Productivity of chickpeas in five different zones.
3. To study the Spatial Shift in the area under chickpeas cultivation.
4. To find the major reasons for the Spatial Shift.

5 Data and Methodology

The study is based on the secondary data collected from the Directorate of Economics and Statistics (DES), Ministry of Agriculture and Indian Institute of Pulses Research. All India wise and State wise yearly data on Area, Production and Yield of chickpeas were collected from 1964 to 2017. To examine the trends in Area, Production and Productivity of chickpeas Compound Annual Growth Rate were used.

Average Annual growth Rate (AAGR) has been used to calculate the growth rate for the period 1964–1970 (for only 6 observations), as follows:

$$\text{AAGR} = \frac{\text{Present Value} - \text{Past Value} \times 100}{\frac{\text{Past Value}}{\text{Number of Years}}}$$

Compound Annual Growth Rate (CAGR) has been calculated using *Semi-Log Regression Method.* (Basic Econometrics, Damodar N. Gujarati). The Compound Annual growth rate formula is mathematically expressed as:

$$\mathbf{Y_t = Y_0(1 + r)^t}$$

Where r is the compound rate of growth of Y. Taking the natural logarithm of the equation,

$$\ln Y_t = \ln Y_0 + t \ln(1 + r)$$

Let,

$$\beta_1 = \ln Y_0$$

$$\beta_2 = \ln(1 + r)$$

$$\beta_2 = \frac{\text{Relative change in regressed}}{\text{Absolute change in regressor}}$$

The equation can be rewritten as, $\mathbf{\ln Y_t = \beta_1 + \beta_2 t}$.

Here, β_1 and β_2 are linear and this is a linear regression model with linear parameters.

The regressed is the logarithm of Y i.e. Area, Production and Productivity. The regressor is the time i.e. number of years. The Slope Coefficient measures the constant proportional or relative change in Y for a given absolute change in the value of the regressor.

The Compound Annual Growth Rate is given by, $\mathbf{r = (antilog\ \beta_2 - 1) \times 100}$.

Table 1 Division of area under study

Southern zone	Western zone
Andhra Pradesh Karnataka Kerala Tamil Nadu	Rajasthan Gujarat Maharashtra
Northern zone	Eastern zone
Himachal Pradesh Haryana Uttar Pradesh Punjab	Assam Bihar Orissa Jharkhand West Bengal
Central zone	
Madhya Pradesh, Chhattisgarh	

Table 2 Division of time period under study

S. No.	Name of the period	Time period
1	Embryonic stage of Green Revolution	1960–1970
2	Mature stage of Green Revolution	1971–1990
3	Pre-trade spike period	1991–2000
4	Post-trade spike period	2001–2017

5.1 Organisation of the Study

The study area has been divided into five different zones based on their geographical locations as follows in Table 1.

The Study period has been divided into five time periods as follows (Table 2).

6 Analysis and Results

6.1 Area, Production and Productivity of Chickpeas (All India Level)

At all India level, total area under chickpeas cultivation witnessed countless fluctuations from 1950 to 2018. The overall trends in area, production and yield of chickpeas during the study period shows varying trends. The CAGR of Area, Production and Yield of chickpeas is given in Table 3.

During the decades of 1950s, growth in production of chickpeas was very high led by both increase in area as well as yield. In the event of post-independence, lot of uncultivated area was brought under cultivation that led to rapid increase in area under chickpea as well. Similarly, with the development work oriented towards agriculture

Table 3 Compound annual growth rate (%) in National Chickpea area, production & yield

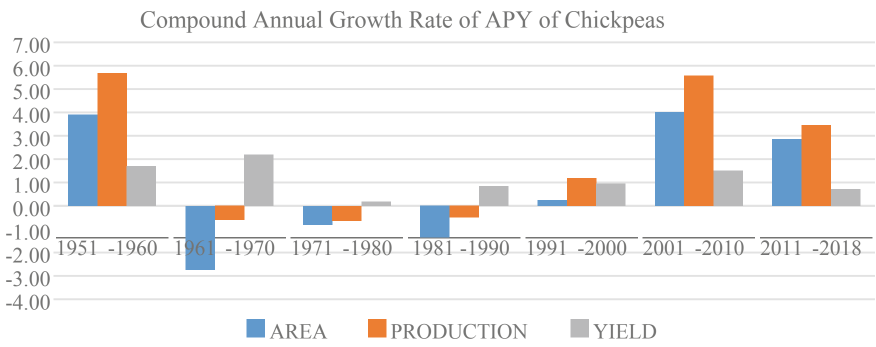
Period	Area	Production	Yield
1951–1960	3.92** (4.0)	5.68** (3.6)	1.71^{NS} (1.5)
1961–1970	−2.73*** (−5.1)	−0.60^{NS} (−0.3)	2.19^{NS} (1.3)
1971–1980	−0.81^{NS} (−0.9)	−0.63^{NS} (−0.3)	0.17^{NS} (0.1)
1981–1990	−1.36^{NS} (−1.4)	−0.50^{NS} (−0.3)	0.85^{NS} (0.9)
1991–2000	0.25^{NS} (0.1)	1.19^{NS} (0.5)	0.95^{NS} (1.2)
2001–2010	4.02*** (7.5)	5.58*** (4.9)	1.51^{NS} (2.1)
2011–2018	2.86^{NS} (1.7)	3.46^{NS} (1.1)	0.72^{NS} (0.4)
1951–2018	−0.19* (−1.9)	0.64*** (4.7)	0.82*** (12.2)

Note Figures in parentheses are respective 't' values
*: 0.05 alpha levels, **: 0.01 alpha levels, ***: 0.001 alpha levels, ^{NS}: Not Significant

in the first two five-year plans, there was rapid increase in productivity of most of the commodities leading to increase in yield rate of chickpea as well. However, there was a decreasing trend in area during sixties, which is attributed to the introduction of Green Revolution. During this period the total area under chickpeas cultivation in Northern and Eastern states of the country started decreasing as they shifted to more water intensive crops like wheat and rice. During the period of seventies, eighties and nineties, the total area under chickpeas cultivation is seen fluctuating. This was because the area under chickpeas cultivation in Northern and Eastern states started decreasing while that of Southern, Central and Western States started increasing.

After 2000s, there was an increasing trend in the total area under Chickpeas cultivation. With just 5.91 million hectares during 2002, the total area increased to 10.56 million hectares in 2017–18. The increase in the total area was found in Southern, Central and Western Zones of the Country. The area increase was especially witnessed during the period of implementation of National Food Security Mission post 2007. There was hardly any significant growth in yield level, although yield growth was found positive in almost all the decades without any exception. Combined with positive and significant growth in area, the production witnessed significant growth in the post 2000s.

It is visible from Graph 1 that growth in area as well as yield leading to growth in production mostly visible in the decades of 1950s and 2000s, which slightly carried on in the decade of 2010 as well (albeit data for the period of 2010 decade is only up to 2018). The period of four decades in between has seen mostly either negative or no growth in area and mostly insignificant growth in yield rate leading to positive but non-significant growth in production of chickpeas. The Explanation of trend growth in area, production and yield of chickpeas at all India lies with the spatial changes or dynamic changes taking place within different zones as the country is divided into five zones. This is explained by zone wise analysis as follows.



Graph 1 Compound annual growth rate (%) in National Chickpea area, production and yield

6.1.1 Northern Zone

During the period before Green Revolution, Chickpeas were widely cultivated in Northern states like Uttar Pradesh, Punjab and Haryana. Larger areas of land in these states were occupied for the cultivation of pulses, especially chickpeas. As green revolution started during 1965, the total crop area under chickpeas in these states started decreasing (Fig. 1 and Graph 2). One major reason for this decreasing trend was the improved irrigation facilities in the northern states which made them to shift from rain fed chickpeas cultivation to more water intensive crops like wheat and rice which yielded much better profit compared to chickpeas. It is seen from Fig. 1 that total area under chickpeas declined incessantly whereas the slope of decline was much steeper right from the beginning of 1960s until the end of 1990s. The decline started phasing out in the early 2000s and there is slight up-turn visible after the mid 2010s.

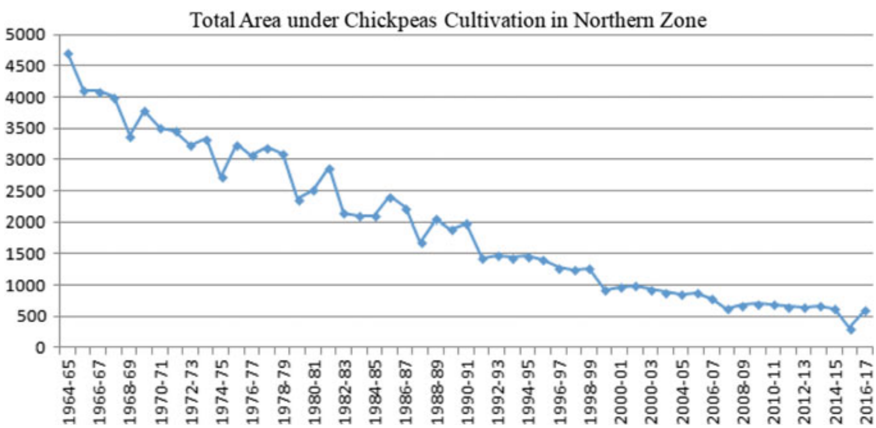
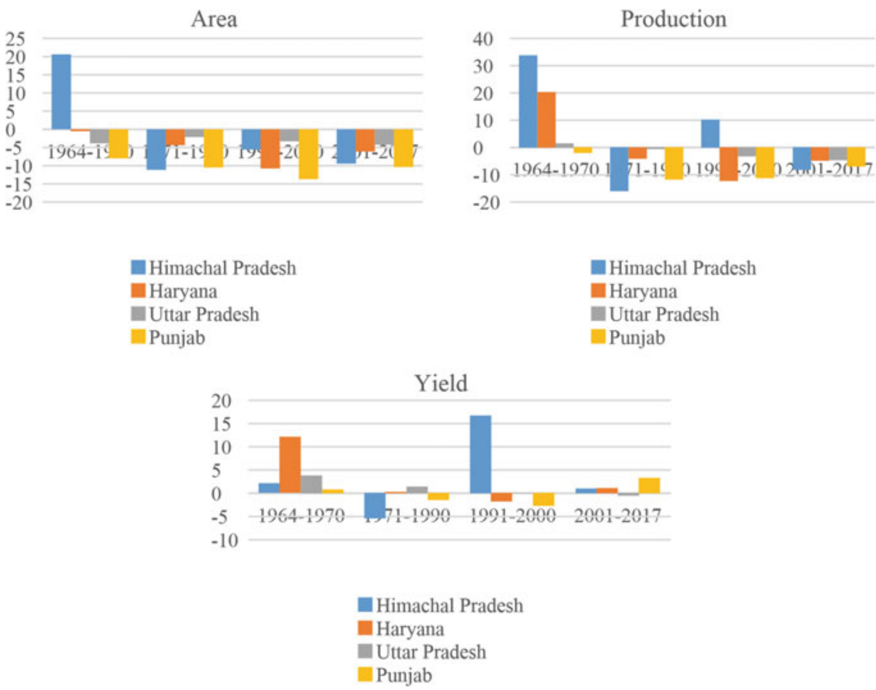


Fig. 1 Total area under Chickpeas cultivation (000'ha) in Northern Zone (1964–2016)



Graph 2 CAGR of area, production and productivity of Northern Zone

The Compound Annual Growth Rate of area under Chickpeas Cultivation is as follows (Graph 2).

The total area under chickpeas in northern zone came down from 4.7 million hectares in 1964–65 to 2.3 million hectares in 1971–72 and still reduced to 0.6 million hectares during 2016–17. Punjab witnessed the greatest decrease in area and production by −0.3 million hectares and −0.38 million tonnes, respectively during the embryonic stage of green revolution. It is seen from Fig. 2 that throughout the period there was decrease in area under chickpeas cultivation in the northern zone. Table 4 shows CAGR in area, production and yield in all the northern zone states. It is clearly visible that area growth was significantly negative in all the four states in the northern zone in the post green revolution period and the same continues till date. Unlike area, the yield growth rate has been fluctuating leading to negative growth rate in production as well with only exception of Himachal Pradesh where production growth was positive but insignificant in the 1990s. Thus, reduction in area and no significant increase in productivity has contributed to the reduced production of chickpeas in northern zone.

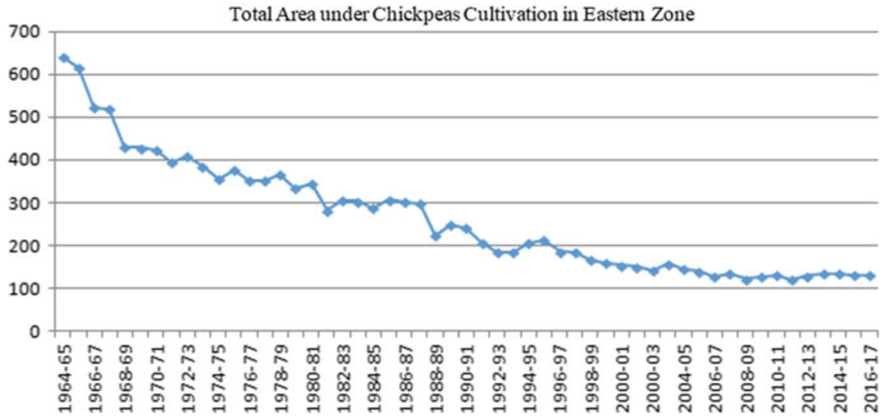


Fig. 2 Total area under Chickpeas cultivation (000'ha) in Eastern Zone (1964–2016)

Table 4 CAGR of area, production and yield of Chickpeas cultivation in Northern Zone

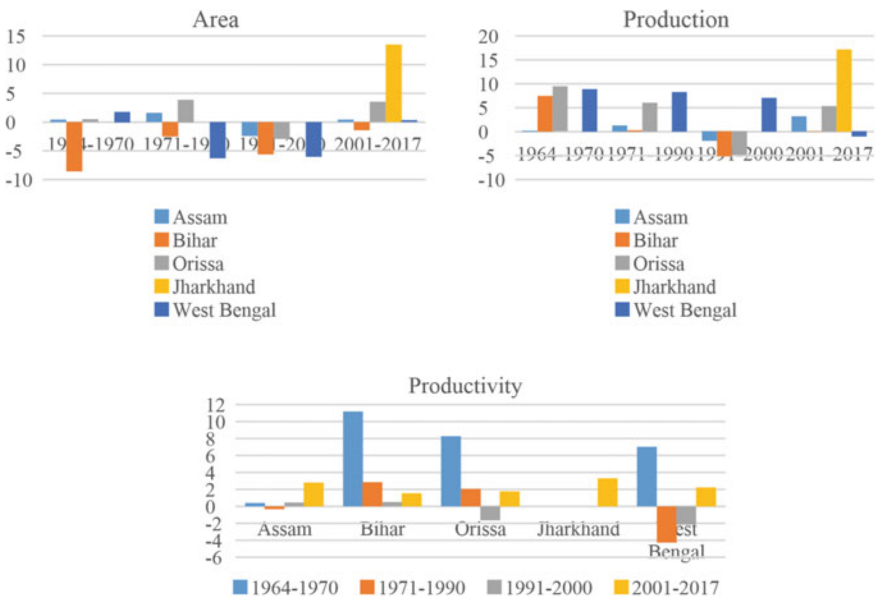
State		1964–1970	1971–1990	1991–2000	2001–2017
Himachal Pradesh	A	20.5	−11.17*** (−7.3)	−5.53* (−2.3)	−9.42*** (−5.7)
	P	33.7	−15.99*** (−5.0)	10.19^{NS} (2.1)	−8.30** (−3.1)
	Y	2.08	−5.41* (−2.4)	16.66* (2.9)	0.98^{NS} (0.5)
Haryana	A	−0.52	−4.38** (−3.5)	−10.66* (−2.5)	−5.99** (−3.5)
	P	20.24	−4.09^{NS} (−1.8)	−12.33^{NS} (−2.0)	−4.93* (−2.3)
	Y	12.06	0.30^{NS} (0.2)	−1.87^{NS} (−0.7)	1.12^{NS} (0.8)
Uttar Pradesh	A	−3.77	−2.08*** (−11.8)	−3.30*** (−11.1)	−4.13*** (−4.1)
	P	1.53	−0.68^{NS} (−1.0)	−3.27** (−3.7)	−4.71* (−2.6)
	Y	3.76	1.41* (2.1)	0.07^{NS} (0.07)	−0.59^{NS} (−0.6)
Punjab	A	−7.90	−10.47*** (−10.2)	−13.61*** (−7.1)	−10.27*** (−15.1)
	P	−2.12	−11.72*** (−8.6)	−11.21*** (−5.5)	−6.92*** (−7.8)
	Y	0.79	−1.54^{NS} (−1.7)	2.77* (2.2)	3.26^{NS} (5.3)

Note Figures in parentheses are respective 't' values
*: 0.05 alpha levels, **: 0.01 alpha levels, ***: 0.001 alpha levels, ^{NS}: Not Significant

6.1.2 Eastern Zone

Eastern Zone of India was considered to be the most prosperous region till 1950s. Success of Green Revolution in northern and western zone in India led this zone lose its position as the leading producer. In the eastern zones, there were many issues like fragmented and small land holdings, technological, socio-economic, institutional, organizational, and developmental problems. Area under chickpeas cultivation in the eastern states have been on a decreasing trend from 1964 up till now (Fig. 2 and Graph 3). The overall area in eastern zone decreased from 6.4 million hectares in 1964–65 to 3 million hectares in 1986–87 and to just 1.3 million hectares in 2016–17. Like in the case of northern zone, decline in area was steeper in the post green revolution period but slight flatter in the post liberalisation era (Fig. 2).

The CAGR of area, production and yield in eastern zone for chickpeas is summarized in Table 5. Bihar, Orissa and West Bengal being major pulse growing states witnessed decreasing trend in area throughout except Orissa where decreasing trend was prevalent in the 1990s. Similarly, Assam also observed negative growth in area albeit it was not significant. The production growth was negative or insignificant in Bihar, West Bengal and Assam, while Odisha was the only exception. As rice and wheat cultivation was more profitable, there was a shift towards these crops. Chickpeas cultivation decreased because of insignificant growth in yield rate, epidemic of blight and lack of HYV seeds. The crop shifted from irrigated areas to more rainfed areas giving way for cultivation of rice and sugarcane in irrigated belts.



Graph 3 CAGR of area, production and productivity of Chickpeas

Table 5 Compound annual growth rate of area under Chickpeas cultivation in Eastern Zone

State		1964–1970	1971–1990	1991–2000	2001–2017
Assam	A	0.4	1.58^{NS} (1.9)	-2.42^{NS} (−1.9)	0.38^{NS} (0.7)
	P	0.18	1.26^{NS} (1.6)	-2.01^{NS} (−1.5)	3.17* (2.9)
	Y	0.36	−0.31* (−2.5)	0.41^{NS} (1.0)	2.79** (3.8)
Bihar	A	−8.59	−2.50*** (−9.2)	−5.61** (−4.5)	−1.38** (−3.3)
	P	7.47	0.28^{NS} (0.6)	−5.16* (−2.6)	0.08^{NS} (0.09)
	Y	11.18	2.83*** (6.0)	0.47^{NS} (0.2)	1.49* (2.2)
Orissa	A	0.46	3.89*** (5.6)	-2.93^{NS} (−1.8)	3.49*** (4.6)
	P	9.4	5.97*** (8.3)	-4.90^{NS} (−2.1)	5.32*** (6.3)
	Y	8.23	2.03*** (4.9)	-1.62^{NS} (−1.6)	1.76*** (7.9)
Jharkhand	A	–	–	–	13.43*** (4.9)
	P	–	–	–	17.14** (4.6)
	Y	–	–	–	3.27* (2.8)
West Bengal	A	1.78	−6.28*** (−6.9)	−6.02*** (−5.3)	0.27^{NS} (0.4)
	P	8.86	8.26* (3.2)	7.05^{NS} (1.8)	-1.11^{NS} (−0.7)
	Y	6.99	−4.27** (−3.7)	-2.13^{NS} (−1.8)	2.22** (4.03)

Note Figures in parentheses are respective 't' values
*: 0.05 alpha levels, **: 0.01 alpha levels, ***: 0.001 alpha levels, NS: Not Significant

6.1.3 Southern Zone

In the Southern Zone, during the embryonic stage of Green Revolution, the major chickpeas producing state was Karnataka. The other states that cultivated chickpeas include, Andhra Pradesh and Tamil Nadu. In the southern zone of the country there are not much improved irrigation facilities resulting in less use of inputs like fertilisers, machineries and HYV seeds. Being primarily dependent on rainfall for agriculture, these states started shifting from more water intensive crops to less water intensive crops, e.g., pulses. Chickpeas are also low input requiring crops. After 1990s the overall area under chickpeas cultivation in southern zone started increasing. The increasing trend in the area under chickpeas cultivation over the years can be observed from Fig. 3. Chickpeas area increased at a rapid pace in the southern zone especially during the post 2006 after initiation of the NFSM Programme.

The CAGR of area, production and productivity of chickpeas in southern zone is given in Table 6 and Graph 4.

Only 0.2 million hectares of land was under chickpeas cultivation during 1964–65. During 1990s there was a rapid increase in the production of chickpeas in Andhra Pradesh and Karnataka because of both very high and significant increased productivity and increased area (Table 6). Increased productivity is attributed to the introduction of short duration, disease resistant chickpeas varieties in southern zone. Andhra Pradesh farmers shifted to chickpeas from cotton, chillies and tobacco cultivation as chickpeas cultivation requires less labour and investment. Improved short

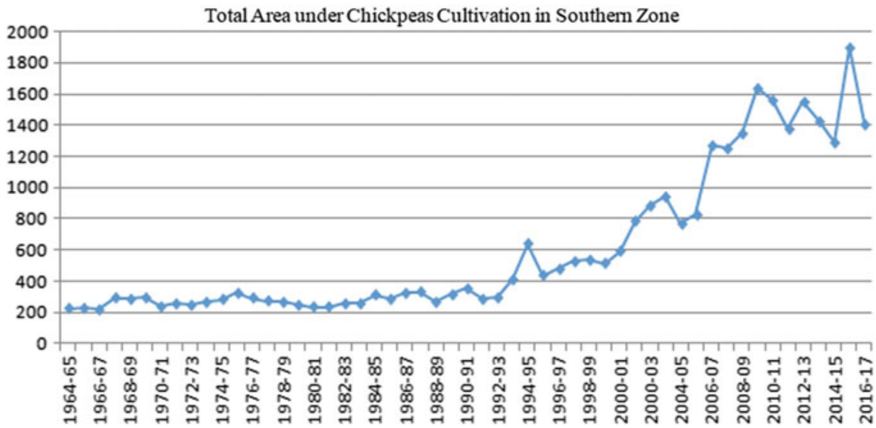


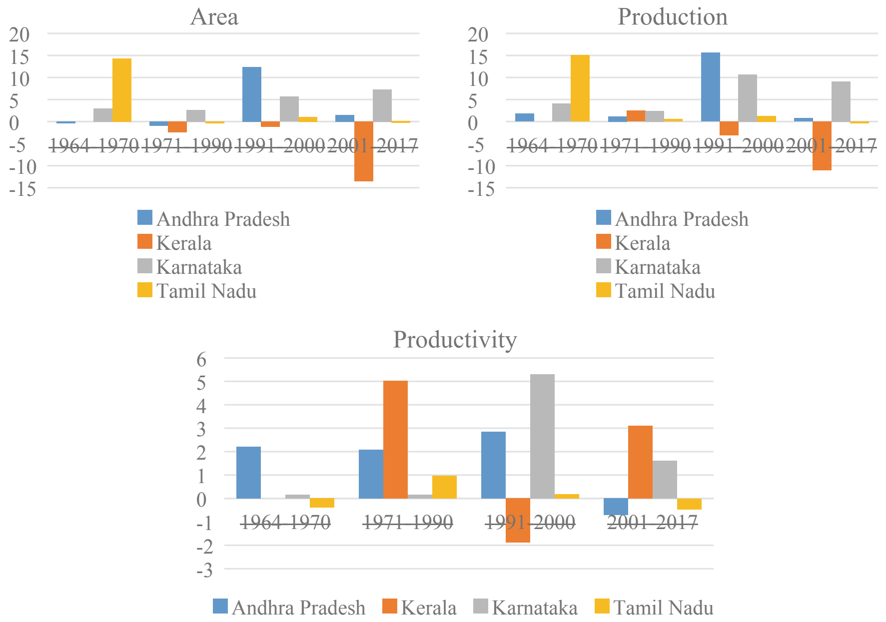
Fig. 3 Total area under Chickpeas cultivation (000'ha) in Southern Zone (1964–2016)

Table 6 CAGR of area, production and productivity of Chickpeas in Southern Zone (1964–2017)

STATE		1964–1970	1971–1990	1991–2000	2001–2017
Andhra Pradesh	A	−0.4	−0.91^{NS} (−1.3)	12.41** (4.7)	1.50^{NS} (1.1)
	P	1.8	1.21^{NS} (0.9)	15.63* (3.1)	0.77^{NS} (0.4)
	Y	2.2	2.09* (2.3)	2.85^{NS} (0.8)	−0.71^{NS} (−0.8)
Kerala	A	–	−2.41*** (−8.9)	−1.19^{NS} (−0.4)	−13.56** (−4.7)
	P	–	2.47*** (4.8)	−3.06^{NS} (−0.8)	−11.04** (−3.5)
	Y	–	5.02*** (13.1)	−1.88^{NS} (−0.8)	3.11^{NS} (1.9)
Karnataka	A	3.0	2.61*** (4.2)	5.64* (2.4)	7.28*** (7.8)
	P	4.07	2.42^{NS} (1.9)	10.71* (3.1)	9.08*** (7.03)
	Y	0.15	0.15^{NS} (0.15)	5.31* (2.5)	1.62^{NS} (1.6)
Tamil Nadu	A	14.35	−0.43^{NS} (−0.3)	1.09^{NS} (0.3)	0.15^{NS} (0.1)
	P	15.06	0.55^{NS} (0.4)	1.29^{NS} (0.3)	−0.31^{NS} (−0.2)
	Y	−0.39	0.96* (2.1)	0.19^{NS} (0.3)	−0.46* (−2.2)

Note Figures in parentheses are respective 't' values
*: 0.05 alpha levels, **: 0.01 alpha levels, ***: 0.001 alpha levels, ^{NS}: Not Significant

duration and *Fusarium* wilt resistant varieties also fetched good price in the local market. During the end of the study period almost 2 million hectares of land has come under chickpeas cultivation. Improved varieties of chickpeas have led to the shift from sorghum and ragi to chickpea in Karnataka. Kerala on the other hand experienced negative growth in area and insignificant growth in yield rate and Tamil Nadu underwent insignificant growth in area as well as productivity during the same time period.



Graph 4 CAGR of area, production and productivity of Chickpeas in Southern Zone (1964–2017)

6.1.4 Western Zone

The area under chickpeas in the Western Zone has remained fluctuating over the study period. In an overall frame the area under this zone has increased. There was increased area during 1999, which fell down very rapidly in the next few years and again started increasing later in 2000s. One of the major reasons for such fluctuations was the epidemic of blight in north western states. Ascochyta blight during 1981–83 damaged much of the crops and there was high yield loss which resulted in shift in area under chickpea crop. Area under chickpeas from 1964 onwards is displayed in Fig. 4. It is visible from the figure that although there existed ups and downs in area under chickpeas in the western region but overall there was positive trend in area under chickpeas during the study period. The positive trends in area especially increased in the post NFSM period along with increase in annual fluctuations. The short term fluctuations occur mainly due to the crop being sown in rainfed areas and rising climate uncertainties in terms of irregular and untimely rainfall.

The Compound Annual Growth Rate of area, production and productivity of chickpeas in western states is given in Table 7 and Graph 5. It is clear from the graph that there was hardly any consistent growth in area and yield during the period of 1970s, 1980s and 1990s. However after 2000, both the area and productivity has increased which led to an increased production of chickpeas. This is because of the introduction of chickpeas varieties that are disease resistant and pest resistant. Area under chickpeas cultivation in the western zone though fluctuating has increased

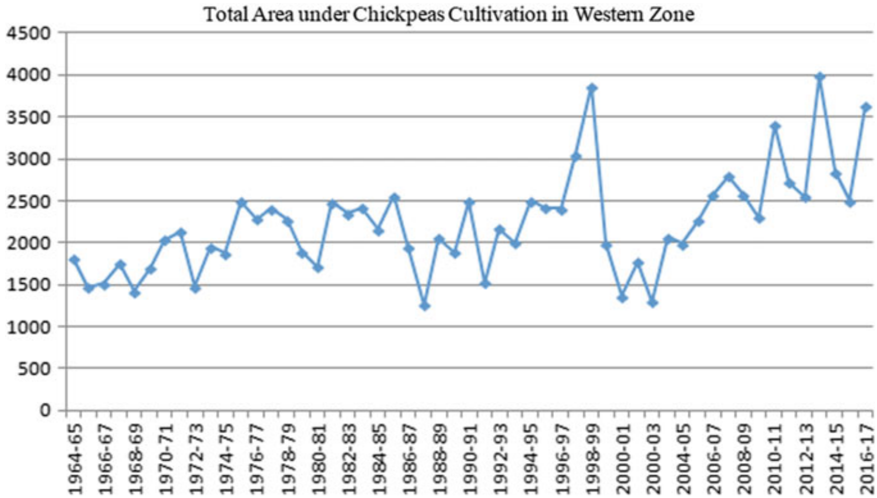


Fig. 4 Total area under Chickpeas cultivation (000'ha) in Western Zone (1964–2016)

Table 7 CAGR of area, production and productivity of Chickpeas in Western States (1964–2017)

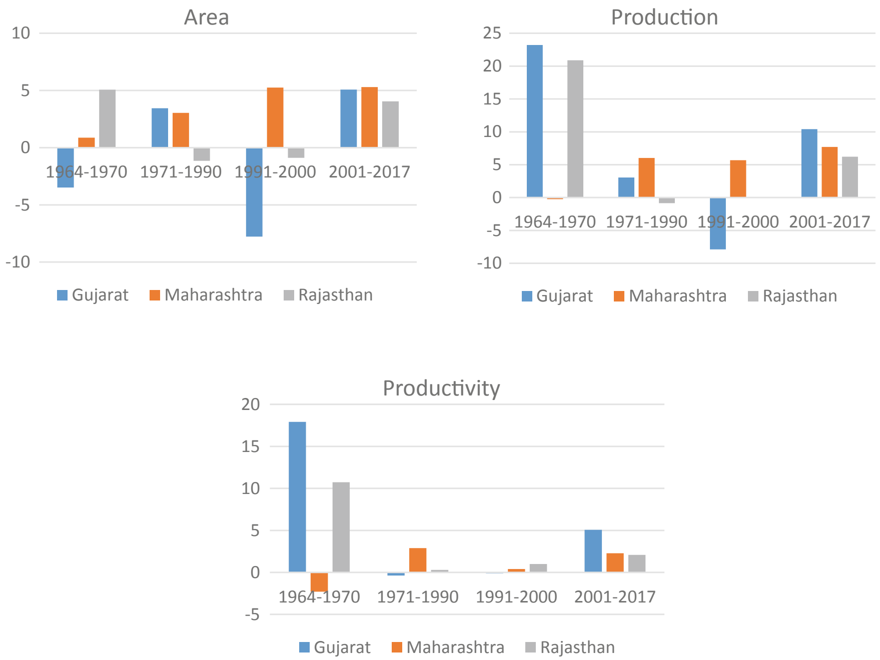
STATE		1964–1970	1971–1990	1991–2000	2001–2017
Gujarat	A	−3.48	3.45^{NS} (1.73)	−7.77^{NS} (−1.1)	5.08* (2.2)
	P	23.21	3.06^{NS} (1.2)	−7.87^{NS} (−0.9)	10.41** (3.4)
	Y	17.91	−0.38^{NS} (−0.4)	−0.11^{NS} (−0.1)	5.06^{NS} (6.4)
Maharashtra	A	0.87	3.04*** (5.8)	5.25* (2.9)	5.29*** (6.1)
	P	−0.23	6.03*** (4.5)	5.68^{NS} (1.6)	7.71*** (4.7)
	Y	−2.29	2.89** (3.3)	0.40^{NS} (0.2)	2.28* (2.5)
Rajasthan	A	5.06	−1.15^{NS} (−1.2)	−0.89^{NS} (−0.1)	4.05* (2.5)
	P	20.89	−0.85^{NS} (−0.6)	0.09^{NS} (0.01)	6.22** (3.2)
	Y	10.73	0.30^{NS} (0.4)	1.00^{NS} (0.5)	2.08^{NS} (1.7)

Note Figures in parentheses are respective 't' values
*: 0.05 alpha levels, **: 0.01 alpha levels, ***: 0.001 alpha levels, ^{NS}: Not Significant

from 1.8 million hectares during 1964–65 to 3.6 million hectares during 2016–17. As the improved and disease resistant varieties got popularised through frontline demonstrations in these western states, there was a significant increase in production and yield.

6.1.5 Central Zone

The Central Zone includes Madhya Pradesh and Chhattisgarh although area, production and yield data for Chhattisgarh is available only in post 2000, after reorganisation



Graph 5 CAGR of area, production and productivity of Chickpeas in Western States (1964–2017)

of Madhya Pradesh and Chhattisgarh. The total area under Central Zone has been on an increase since 1965. Madhya Pradesh is the largest contributor to total chickpea production in India both in terms of area and production. Green Revolution has not affected chickpeas production in terms of area. The total area in Madhya Pradesh has increased from 1.48 million hectares in 1964–65 to 3.2 million hectares in 2016–17. At the same time production has gone up from 0.8 million tonnes in 1964–65 to 3.54 million tonnes in 2016–17 and yield has gone up from 575 kg/ha to 1100 kg/ha during the same time period. This region is one of the most important regions in the country where pulses development programme can succeed in the long run. Framers interest have started shifting from cereals cultivation to pulses cultivation especially chickpeas after pigeon peas. Hence it is a state with high growth potential in chickpeas (Fig. 5, Graph 6; Table 8).

Since the data for Chhattisgarh is available only for post 2000s, the growth rate of chickpeas cultivation has been calculated only for the last season. During 2001–2017, total production has increased from 0.12 million tonnes to 0.36 million tonnes in Chhattisgarh as the area has increased from 0.17 million hectares to 0.31 million hectares and the yield has increased from 735 kg/ha to 1171 kg/ha. This increased production is attributed to the increased area and introduction of new varieties of seed for cultivation. Soya bean-chickpea rotation has become popular in Madhya Pradesh.

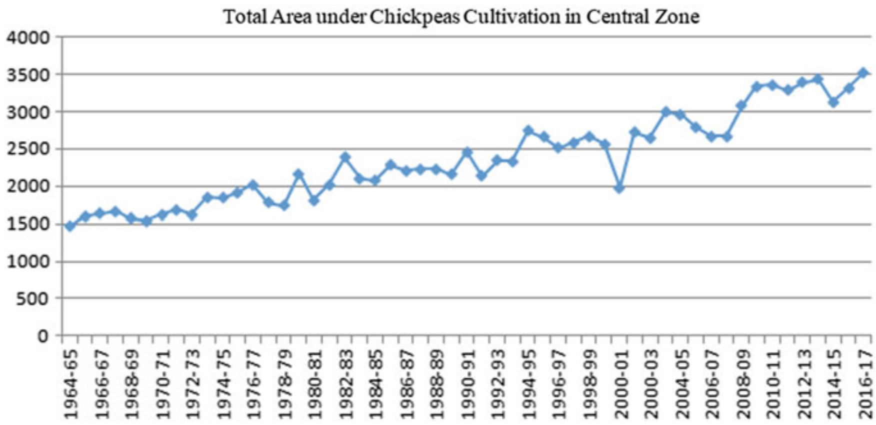
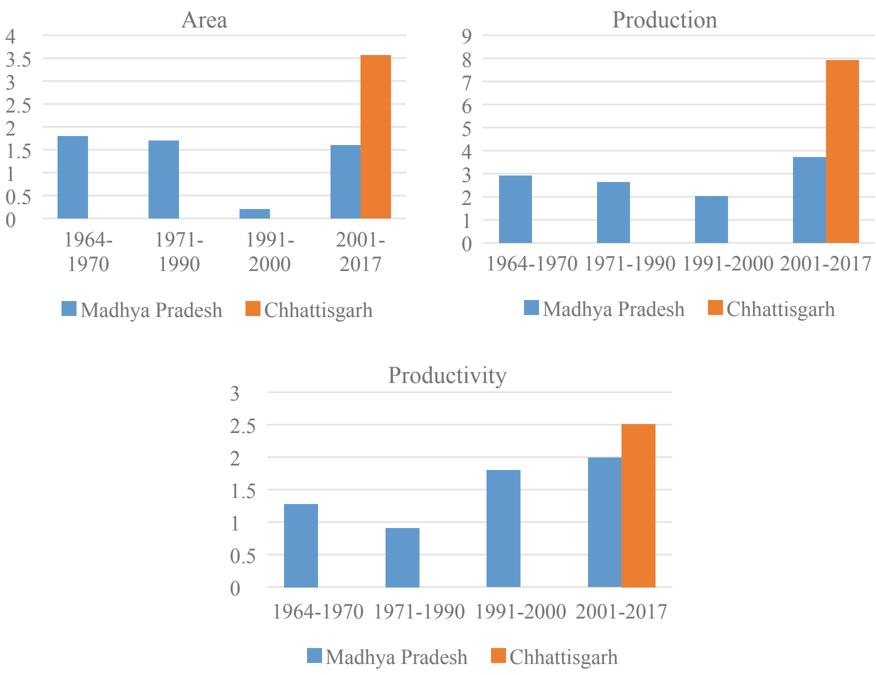


Fig. 5 Total area under Chickpeas cultivation (000'ha) in Central Zone (1964–2017) (Data for Chhattisgarh is not available till 2000)



Graph 6 CAGR of area, production and productivity of Chickpeas in Central Zone (1964–2017)

Table 8 CAGR of Area, Production and Productivity of Chickpeas in Central Zone (1964–2017)

State		1964–1970	1971–1990	1991–2000	2001–2017
Madhya Pradesh	A	1.8	1.7*** (6.4)	0.2^{NS} (0.2)	1.6*** (4.5)
	P	2.92	2.64*** (4.9)	2.02^{NS} (1.05)	3.71*** (4.13)
	Y	1.28	0.91^{NS} (1.8)	1.80^{NS} (1.87)	1.99** (3.1)
Chhattisgarh	A	–	–	–	3.56*** (12.9)
	P	–	–	–	7.92** (3.6)
	Y	–	–	–	2.51** (2.6)

Note Figures in parentheses are respective 't' values
*: 0.05 alpha levels, **: 0.01 alpha levels, ***: 0.001 alpha levels, ^{NS}: Not Significant

7 Spatial Shift in the Area Under Chickpeas Cultivation

From the beginning of the Green Revolution till 2017 there has been an increasing trend in the area under chickpeas cultivation in central, southern and western zones of the country. At the same time there was a declining trend in the area in the northern and eastern zones. This shift in the area from northern and eastern zones to southern, western and central zones can be represented as below. The major reasons for the spatial shift and its remedies are discussed in the next section. The shift from rainfed pulses to more water intensive crops has reduced the area under chickpeas cultivation in these states (Fig. 6).

The production of chickpeas in the northern and eastern states started decreasing with the introduction of Green Revolution. There were no HYV seeds in pulse crops during that time to enhance the production of chickpeas. No technological breakthroughs were present during this period in these zones to improve the production of chickpeas. There were no assured returns from pulse crops as they are highly affected by the pests. More rainfall also reduced the production of chickpeas. No government policies to procure the crop had also led to the decreased production in these areas (Fig. 7).

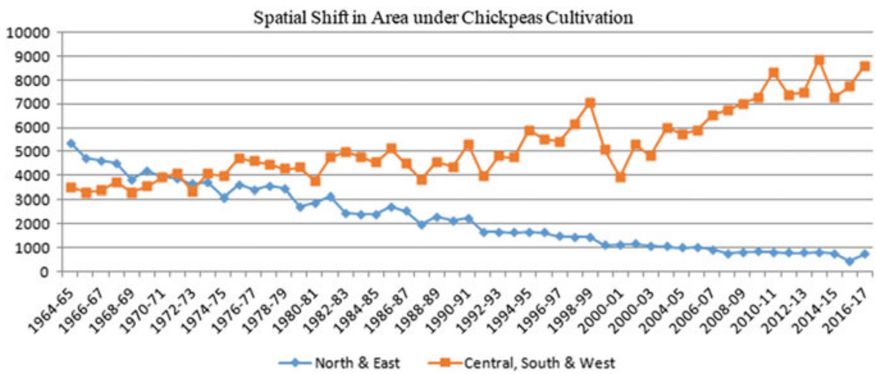


Fig. 6 Spatial shift in area under Chickpeas cultivation (000'ha)

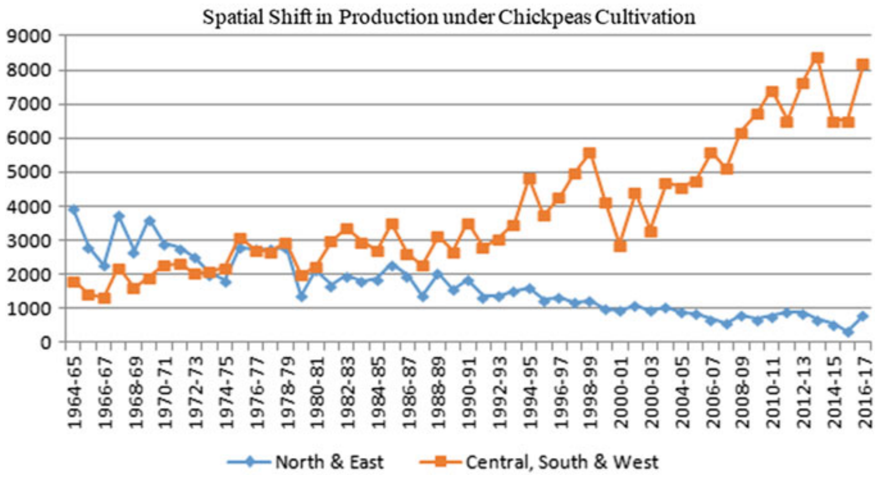


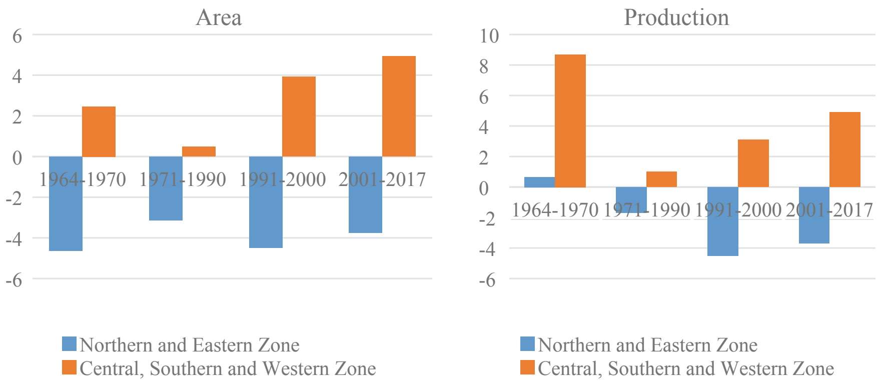
Fig. 7 Spatial shift in production of Chickpeas (000' metric tonnes)

The Compound Annual Growth rate of area and production of chickpeas in northern and eastern zone together vs. central, southern and western zone is presented in Table 9 and Graph 7. There was clearly negative and significant growth rate in area as well as production of chickpeas in the north and eastern zones. On the other hand, there was positive but insignificant growth in area and production till the 1990s for chickpea in central, south and western zones. However, the growth in area as well as production was positive and significant in the 2000s in this zone indicating increase in overall chickpea production during the period of 2000s especially with the implementation of various pulse programmes.

Table 9 CAGR of area, production of Chickpeas in different zones

Shifting Zones		1964–1970	1971–1990	1991–2000	2001–2017
Northern and Eastern Zone	A	−4.63	−3.14*** (−8.8)	−4.48** (−5.1)	−3.76*** (−5.3)
	P	0.66	-1.69^{NS} (−1.9)	−4.51** (−3.9)	−3.69* (−2.7)
Central, Southern and Western Zone	A	2.46	0.48^{NS} (0.9)	3.92^{NS} (1.5)	4.93*** (7.2)
	P	8.69	0.99^{NS} (1.3)	3.11^{NS} (1.2)	4.91*** (6.8)

Note Figures in parentheses are respective 't' values
*: 0.05 alpha levels, **: 0.01 alpha levels, ***: 0.001 alpha levels, ^{NS}: Not Significant



Graph 7 CAGR of area, production of Chickpeas in different zones

8 Determinants of Area and Yield of Chickpeas

The supply response function of chickpea can be summarised in terms of area response and yield response as these two together determine production. For fitting up supply response in chickpea, a least square equation model has been used for the historical data period from 1980–81 to 2017–18. The set of area response and yield response equations have been estimated with all possible determinants. The specification of equations estimated are given:

(i) Area	= f (P_i, P_j, Rain, Irrg, Lagged)
(ii) Yield Where	= f (P_i, Rain, Irrg, Fert, Trend)
P_i	Is real domestic (farm harvest) price
P_j	Is real competing crop price
Rain	Is rainfall—annual rainfall as a percentage of normal rainfall
Irrg	Is percentage of area under irrigation
Fert	Is fertilizer use in kgs per hectare
Lagged	Is lagged dependent variable
Trend	Is time trend representing technology

The factors influencing area and yield were both price and non-price factors like the lagged area under the crop, price of the crop relative to the price of other commodities competing with it for land and other inputs, irrigated area, and prices of inputs relative to crop price. Rainfall is the factor representing climate and other environmental factors. Since regression is run in double log format, the coefficients are directly the elasticities. Result of regression analysis are presented in Tables 10 and 11 for area and yield, respectively. It is seen from the statistics in tables that own price has a direct impact on area cultivated under chickpeas. With ten per cent increase in price of chickpea, there is approximately 2% increase in area under chickpea. On the opposite, with ten per cent increase in competing crop price, area under chickpea declines by 2%. The impact of irrigation on area cultivated of chickpea is negligible as this variable is highly significant indicating the rain fed nature of area under chickpea crop. However, climate is a dominant determinant of area under this pulse crop. Normal rainfall leads to increase in area under chickpea whereas below normal rainfall and high fluctuations and untimely rainfall leads to reduction in area under chickpea. Turning to the yield determinants, increase in real price of chickpea indirectly leads to increase in productivity through better utilization of resource inputs. Similarly, higher use of fertilizer results in better productivity of chickpea. Normal rainfall not only increases area under chickpea but it also leads to incremental effect on productivity although better irrigation facilities may divert land as well as other input resources away from chickpea. Coefficient for time trend indicates increase in productivity of chickpea over time also reflecting technology improvement like high yielding variety seeds over time. The value of R^{-2} and F statistics indicate the good fitness of regression for both area as well as yield indicating determinants well explaining the dependent variable.

Table 10 Factors determining area sown under Chickpeas—All India Dependent Variable—Log area under Chickpea

Variable	Coefficient	t-Statistic	Prob.
Log Real FHP_rabi pulses	0.194	(1.6)	0.1196
Log Real FHP_competing crop	−0.187	−(1.5)	0.1567
Log Rainfal	0.537	(3.1)	0.0043
Log Irrigation	−0.035	−(1.2)	0.2458
Log Lagged Dep	0.510	(3.4)	0.0017
Constant	−1.393	−(1.6)	0.126
R-squared		0.63	
Adjusted R-squared		0.57	
F-statistic		10.52	
Prob (F-statistic)		0.00	
D-W stat		1.64	
No of observations		37	

Table 11 Factors determining yield rate for Chickpeas—All India Dependent Variable—Yield rate of Chickpea

Variable	Coefficient	t-Statistic	Prob.
Log Real FHP_rabi pulses	0.01	(1.7)	0.10
Log Fertilizer usage	0.05	(1.9)	0.07
Log Rainfal	0.17	(1.5)	0.14
Log Irrigation	−0.06	−(1.9)	0.06
Time trend	0.01	(6.7)	0.00
Constant	5.63	(10.8)	0.00
R-squared		0.80	
Adjusted R-squared		0.77	
F-statistic		25.85	
Prob(F-statistic)		0.00	
D-W stat		2.49	
No of observations		37	

9 Reasons for Shift and Remedies

1. **Climate Factor**:

The distribution of rainfall in India is uneven and not certain. This causes floods, droughts and famines across different states. States in the northern zone has well improved irrigation facilities while southern and central states rely only on rainfall for its irrigation. Because of improved technology and availability of modern irrigation facilities, states in the northern zone have shifted from pulses cultivation to more water-intensive crops such as wheat and rice. This has shifted the cultivation of pulses like chickpeas from northern and eastern to southern and central India. Since rice and wheat were also procured by the government, these crops give assured returns to the farmers in the north. Southern states with no proper irrigation facilities and primarily being rain fed, started growing pulses. The net irrigated area in the country is 47% while the remaining falls under rainfed ecology. The pulses under irrigation are cultivated in about 37% of the area while 63% of pulses are grown under rainfed conditions (Annual Report 2016–17, Ministry of Agriculture and Farmers Welfare).

2. **Residual Crop**:

Chickpeas are considered to be a residual crop that is grown as an alternative on the marginal lands after the harvest of other crops. This is mainly because of the lack of marketing facilities, policies and schemes that would help the farmers profitable to cultivate chickpeas. Since the maturity period of chickpeas is more than the other crops, the sowing of the next season crop is affected. So, farmers have to pick up the chickpeas before even its physiological maturity, which leads to decline in the yield. Hence, if more short duration varieties are introduced, farmers may expand the area under chickpeas cultivation.

Table 12 Seed replacement ratio of different Pulses (in %)

CROP	2014–15	2015–16	2016–17
Urad	30	34	38
Moong	24	31	34
Arhar	41	45	48
Pea	34	30	30
Gram	**25**	**28**	**32**
Lentil	31	27	35

Source Seed Division, Ministry of Agriculture and Farmers Welfare, Government of India

3. **Seed Replacement Ratio (SRR)**:

Seed Replacement Ratio (SRR) is the ratio of cropped area with the actual quality seeds distributed to farmers to the cropped area with the farm saved seeds. According to various studies conducted every three years new seeds should be sown in order to increase the yield or else the yield will start decreasing. By the current practice in India, the SRR is more than five years (Table 12). This could also be a major reason for the decreasing productivity. As SRR is more than five years, the yields also have a declining trend. Low production is also a constraint for its cultivation. If more High Yielding Quality seeds are distributed, yield would be higher and cultivation of chickpeas may become profitable.

4. **Centralised Seed production**:

In 2013, the regional seed caterers were merged with National Seeds Corporation of India. Now, NSCI supplies seeds to all the states of the country. Country like India with such a diverse climatic condition cannot have a centralised model of seed production. The more suitable model would be a decentralised one. Seed varieties should be distributed according to the state's climatic conditions and topography.

5. **Biotic Stress**:

There are many biotic stresses to the cultivation of chickpeas such as the problem of Wilting, Ascochyta blight, Botrytis grey mould, Dry Root Rot etc. Though there is a rising trend in the area under chickpeas cultivation in southern states, Dry Root rot is emerging as a major problem under the rainfed conditions. These areas should be provided with the Dry Root Rot tolerant varieties such as RSG 974, RSG 202, CSJ 515, CSJ 140, JGK 5, JG 6 and RSG 959. There are also varieties that are intolerant to Ascochyta blight like GNG 469, Himachal Chana 1, RSG 807 etc. (CLL Gowda et al. 2009).

6. **Abiotic Stress**:

Abiotic stresses like Heat, Cold, Salinity and Drought also contribute to the shift of chickpeas area from northern and eastern to central and southern India. With increasing global temperature, heat tolerant varieties are being introduced to enhance the growth of chickpeas. JG 14, JSC 56, JSC 55 are the new heat tolerant short

Table 13 Minimum support prices fixed by the Government (Rs. Per Quintal)

Pulses	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
Tur	3200	3850	4300	4350	4625^	5050^^	5450^	5675
Moong	3500	4400	4500	4600	4850^	5225^^	5575^	6975
Urad	3300	4300	4300	4350	4625^	5000^^	5400^	5600
Gram	**2800**	**3000**	**3100**	**3175**	**3500****	**4000^**	**4400!**	**4620**
Lentil	2800	2900	2950	3075	3400**	3950!	4250*	4475

Source Farmers' Portal
The bold numbers reflect the reference crop for this study
*: Including Bonus of Rs: 100 per quintal, **: Including Bonus of Rs: 75 per quintal, ^: Including Bonus Rs: 200 per quintal, ^^ Including Bonus Rs: 425 per quintal ! : Including Bonus of Rs: 150 per quintal

duration chickpeas varieties. RSG 888, Vijay are the drought tolerant varieties for rainfed conditions in southern and central India. Karnal Chana 1 is the variety that has tolerance to mild salinity and DCP 92-3 is the variety for high input condition of increased moisture and soil fertility (Gowda et al. 2009).

7. **Profitability**:

The relative profitability of other pulses is higher than the profit from cultivation of chickpeas. The technological advancements in the production of other food grain crops has made their cost of production low compared to chickpeas. The growth of real prices for chickpeas in southern states is more appreciable which helps in the expansion of area under chickpeas in these states (Table 13).

8. **No Technological Revolution**:

There were no technological breakthroughs in the cultivation of chickpeas. Unavailability of improved High Yielding Variety seeds coupled with lack of proper irrigation facilities contribute to the decreasing production in chickpeas. Lack of fertilizers and minerals also leads to reduction in the production.

9. **Early Maturing Varieties**:

ICRISAT-NARS has made several efforts for the availability of early maturing Desi and Kabuli varieties in southern and central India. Desi chickpeas varieties like ICCC 37, ICCV 93954 are suited for southern zones (Gowda et al. 2009). They mature in 90–100 days with an average yield of 1.6–1.8 million tonnes/ha. Kabuli chickpea varieties include seeds like ICCV 2, PKV Kabuli 2, and JGK 1 etc., few of them are resistant to *Fusarium* wilt, which makes it profitable to be grown in southern zones (IIPR 2018).

10. **Yield Instability**:

The real prices of chickpeas in southern states has increased because of high productivity growth. This had made chickpeas a competitor for other dryland crops. But the yield from chickpeas is not stable. Chickpeas are highly sensitive to heat and rainfall. Extreme heat and extreme rainfall will lead to decreased yield as has been seen in our regression results.

11. **Pests and diseases**:

Ascochyta blight, the fungal disease affecting aerial plant parts and *Fusarium* wilt, fungal disease affecting root and stem base are the major diseases that affects chickpeas. There are other fungal and viral diseases like Botrytis gray mold, Alternaria blight, Verticillium wilt, Collar rot, Stunt, Mosaic, Proliferation etc. Bacterial Blight is the bacterial disease common in chickpeas. Beet armyworm is the pest of chickpea in India and Mexico that can go through three to five generations in a year. *Helicoverpa armigera*, common pest in Australia is widely distributed in Asia as well that cause Pod boring (Integrated Pest Management Package for Chickpea, Ministry of Agriculture, GOI).

12. **Government Policies**:

The Government has announced a new MSP scheme PM-AASHA to ensure that farmers growing pulses benefit from this (Press Information Bureau, GOI). The MSP of chickpeas now is Rs. 4620 per quintal (Farmers' Portal, Government of India). With the country being undernourished, bringing chickpeas under Public Distribution System can both enhance its production and meet the nutritional security of the people.

10 Conclusions

The Analysis reveals that there is a shift of area under chickpeas cultivation from northern and eastern to western, central and southern zones of the country. It is important to increase chickpeas production in the conventional chickpeas producing zones by the development of short duration, high yielding varieties that are suitable for these regions. There is a large amount of fallow land (11.6 million hectares) in northern and central India because of lack of irrigation after the harvest of rice (Subbarao et al. 2001). With improved high yielding, disease resistant and short-duration types of chickpeas, there is high chance of expansion of area in these zones. Recent study on climatic conditions has also revealed that with increasing temperatures day by day growing cereal crops like wheat, rice/paddy will also be impossible in the upcoming years. Chickpea breeding programmes need to find varieties that are thermoresistant. Drought and frost are also some serious abiotic stresses in central and southern India. Varieties that are resistant to pod borers can help in enhancing the production of chickpeas.

Government procurement policies through lucrative Minimum Support Prices (MSP) would make it profitable for the farmers who take risks by cultivating chickpeas. They should also be included in Public Distribution System to ensure proper supply and demand. Since chickpeas are rich in protein, they are often affected by pests. Proper crop insurance schemes have to be formulated. Improved infrastructure for safe storage and post-harvest processing can prevent the losses of chickpeas.

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Livelihood Strategies and Agricultural Practices in Khonoma Village of Nagaland, India: Observation from a Field Visit

Niranjan Roy, Avijit Debnath and Sunil Nautiyal

Abstract Forest resources have both economic and ecological significance. However, rapid expansion of non-forest activities at the expense of natural forests has become a serious threat to forest resource all over the world. This paper makes an attempt to understand livelihood strategies, cultivation method and perception about climate change in Khonoma Village of the state of Nagaland, India. The study is based on primary data collected through field survey. Our analysis reveals that all the villagers of Khonoma depend directly or indirectly on agriculture for their livelihood, however, the focus of activity in the present days is shifting towards cash crops. There are mainly two types of cultivation method followed: Jhum Cultivation and Wet Rice Cultivation, the later being the dominant type of cultivation in the present time. The major crops that villagers grow in the present time in Khonoma includes rice, chilli, tomatoes, brinjal, ginger, garlic, pumpkin, cucumber, gourd, yam, lentils, beans, sesame, maize, millet, and job's tears. When asked if they have ever heard of what 'Climate Change' means from any source, around 93% of the respondent said that they have heard about the term mostly from television. Causes of climate change are reported to be different by the different respondents, but none of the respondent considered shifting cultivation causes deforestation thus contributes to climate change.

Keywords Livelihood strategies · Shifting cultivation · Terrace cultivation · Alder tree · Khonoma

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1 Introduction

Forests play an important role in the economic development of a country by providing food, biomass, pulp and paper, rayon, fibers, lac, wooden articles and medicine plants. They also stabilise our ecological system, and provide the gene pool that can protect commercial plant strain against changing conditions of climate. Therefore, forest resources have both economic and ecological significance, and forest soil is the most important asset of forest resources (Agoumé and Birang 2009). However, rapid expansion of non-forest activities at the expense of natural forests has become a serious threat to forest resource all over the world especially in environmentally fragile mountainous areas. According to an estimate, agricultural expansion and infrastructural development contributes 37% of forest degradation, responsible for one third of tropical deforestation of the world (Geist and Lambin 2002). There have been several studies which maintain that method of agricultural practices always has an ecological implication (Ayoubi et al. 2011). For example, shifting cultivation is often considered a dominant factor responsible for forest loss and is the main cause of land degradation especially in India (Ramakrishnan 1992). The shifting cultivation, which is locally known as jhum cultivation, is mostly confined to the tropical rainforests characterised with heavy rainfall, subsistence economy and hot weather. Traditionally, the tribal people in the Northeast India practiced Jhum (shifting cultivation) in the hill slopes as a means of livelihood system. In recent times, Government of India has made several attempts to discourage shifting cultivation in many parts of Northeast India. And one such attempt was to encourage people to take up terrace cultivation. This paper is based on our observation of agricultural practices and livelihood strategies of a village in Nagaland state of Northeast India.

2 Study Area

The study was conducted in Khonoma village (Longitude E94° 2′ 0″ Latitude N25° 39′ 0″) which is situated at the Southern part of the state of Nagaland in India. The village falls under the Kohima district and is located 20 km west of Kohima, the state capital of Nagaland. The village is dominated by Angami-Naga tribe. The geographical area of Khonoma village is about 123 km^2. The village is perched on a hilltop at an altitude of 1200 m from the sea level and is surrounded by hills that are as high as 8000 ft (KTDB 2004: 3). Khonoma village has earned a name for itself in the country as a whole as the first “Green Village” in India, in recognition of the conservation effort by the community. The people of Khonoma are largely dependent on their land and forest for their daily subsistence needs, and with this understanding they have adapted practices and customs which have helped them to utilise their land and forest sustainably. The village has three Khels or local residential units—Thevomia Khel, Merhüma Khel and Semoma Khel. As per census of India, the total population of the village is 1943 persons and it comprises of 424 families (Census of India 2011).

3 Methodology

The method adopted for this study was observation, questionnaire and participatory approach. The primary data was collected through a survey conducted on 60 households (around 14% of total households) randomly selected from the village during the month of August, 2018. The household surveys were undertaken using structured questionnaires that included questions on the underlying drivers of shifting cultivation, i.e., household size, income, assets, credit behaviour, land size, livelihood strategies typology, etc. The questionnaire was prepared before arriving on site, and was subsequently tested with five households in the area to make sure the questions were relevant. In addition to household survey, we have also interviewed various stakeholders consisting of members of Village Council, members of various organizations instituted under the aegis of the Village Council and the general public. Data were analysed using simple statistical and graphical tools.

4 Results

4.1 Livelihood Strategies of Households

Livelihood strategies indicate the way people make their living. Information from communities indicates that all the villagers of Khonoma depend directly or indirectly on agriculture for their livelihood. It fundamentally consists of rice cultivation in the surrounding wetland terrace fields and agricultural products such as vegetables, fruits and cash crops from the jhum fields. In addition to agriculture, the people of Khonoma also practices subsidiary occupation like basketry, carpentry, weaving, woodwork and stone masonry to supplement their earnings. There is also a small section of the community who are employed in government and private institute in different capacities. Table 1 presents a background of the primary occupation practised by the respondents in Khonoma village.

As indicated in Table 1, a total of 65% of respondents showed that they make their living from agriculture. Generally, crop farming was revealed to be the common livelihood strategy that supports most individuals, families and households in the area. However, field observations show that people are mostly practicing rain fed crop farming with small scattered crop fields under supplementary traditional irrigation practices and systems located mainly on mountain slopes and some towards the valley bottoms in the lowlands underneath the forest top mountains. The second major group comprise of Government employees like teachers, school staff, field

Table 1 The primary occupation

Primary occupation	Households (in %)
Agriculture	65
Cottage industries	6
Government/private employee	18
Daily wage labour	2
Business	3
Others	6

Source: Field survey (2018)

workers of Electricity and PHE department and employees in the Primary Health Centre who make up for 18% of the respondents. A number equivalent to 6% of all respondents to the questionnaire interview (Table 1) who responded to the question that was seeking information on how they make their living informed that they make their living out of weaving and selling of ornaments. Our discussion with focused group further indicates that most of these people who earn their livelihood from cottage industry sell their products in the local market on retail basis. Though these people are capable of producing goods of cottage industry in bulk quantity, but due to lack of market and financial assistance, they only produce in tiny quantity. Only 3% of the households make their living by engaging in business like running private taxi, general shops, rice mill and saw mills etc., and 2% are engaged as daily wage labour such as working in the fields of other person, constructing houses, roads etc. There are also respondents who are retired government employees, carpenters, Church employee and social workers. These people jointly contribute 6% of the total respondents.

It is, however, important to note here that the nature of economy is changing in Khonoma village. From the discussion with the focused group, it is observed that though the village has traditionally based on agriculture which has sustained generations, centring on its terrace rice fields and produces from the jhum fields and forests, the focus of activity in the present days is shifting towards cash crops. Another notable change is that the village has become a tourist destination with the declaration of Khonoma as the first "Green Village" of India, and the villagers has an alternative means of earning by running home stays and working as tourist guides.

4.2 Method of Cultivation

There are mainly two types of cultivation method followed in Khonoma Village: Jhum Cultivation and Wet Rice Cultivation. Jhum cultivation is rooted in the customs and beliefs of Khonoma people, thereby influencing their cultural ethos and social fabric. The farmers of Khonoma uphold a sustainable form of jhum cultivation by planting Alder trees in the fields. In this system, they cultivate the land for two years, thereafter, it is abandoned and kept fallow for 8–10 years so that the alder trees in the field restores the fertility of the soil by natural process. The roots of alder trees hold the soil in place, improve the drainage of the soil and, hence, reduce soil erosion. Moreover, being a fast growing plant, alders provide timber and fodder to the villagers especially during those fallow years. Conversation with villagers also reveals that a huge amount of firewood requirement of the households is met from the alder threes grown in the jhum field particularly during dry seasons. The villagers of Khonoma have been gainfully making use of alder tree for hundreds of years by mastering the scientific technique of growing and pollarding the alder tree. Pollarding starts when young trees are 7–10 years old reaches a height of 10 m and diameter of 70–80 cm, and the bark becomes rough and fissured. The trees are pollarded at 2 m above the ground in order to obtain a good sprout and to avoid cattle damage. The subsequent pollarding is done after approximately 5 years of the first pollarding. The second phase of pollarding takes place after approximately 5 years of the first pollarding. During these periods, they allow the coppiced stumps of the trees to grow without any disturbance till the harvest of the first year's crop is finished. After the harvesting is done, alder trees are again flushed down just leaving four to six shoots equally distributed around the top of the stump head. The shoots are then allowed to grow till the next jhum cycle and the same process is repeated.

On the other hand, Wet Rice Cultivation or "panikhetis" as it is popularly known among the Nagas is of two types—Wet Rice Cultivation which is carried out in rainfed lowland areas. In this method of cultivation, bunds are constructed to divide the plot into a number of smaller sections. This is done to keep the crops partially submerged for some parts of the year. Rice is grown followed by wheat, mustard and cold crops. The crops are sown within the sections and keep well irrigated. The second type is wet terrace rice cultivation where the crops are planted in terraces built along the slopes. Rice is the main crop and other crops like wheat, potato, garlic and cabbage are also grown. Terrace cultivation is permanent and ownership of terrace fields is strictly individual. Among the Nagas, the Angamis and the Chakhesangs are well known for their terrace cultivation.

Table 2 gives a brief description of the method of cultivation in the Khonoma village.

Table 2 indicates that out of the 60 respondents, only 10% of the household are now practising jhum cultivation, 60% are practising Wet Rice Cultivation and 25% practise both jhum and Wet Rice Cultivation. However, this was not the picture of cultivation methods in earlier days in the Khonoma village. As revealed by the villagers in the group discussion, most of the households in the village used to rely on jhum cultivation prior to 1970s.

When the villagers were asked why they have shifted to terrace cultivation, most of them stated that compared to jhum cultivation where they have to work on the field throughout the year, terrace cultivation requires work only for some specific months of the year. Secondly, unlike in the jhum cultivation, they do not have to clear the forest land for cultivation as in Wet Rice Cultivation the plot for cultivation is permanently settled. Moreover, jhum field is an easy prey of wild animals.

Table 2 Distribution of households in different cultivation methods

Method of cultivation	No of households	Percentage
Jhum cultivation	6	10
Terrace (wet rice) cultivation	35	60
Jhum + wet rice cultivation	15	25
None	3	5
Total	60	100

Source: Field Survey (2018)

4.3 Major Products Cultivated

Framers of Khonoma traditionally cultivated job's tears, red rice, sticky rice and millets, but the production of these crops has declined in recent time. In earlier days, production of crops was meant for self consumption only and hence these were motivated by household consumption choices. Additionally, crops were grown for the purpose of brewing local rice beers which were being used during their religious rituals, festivals and other social ceremonies. But now with the change in their social, religious and economic structure, the importance of these products have declined for a number of reasons. Firstly, now the villagers grow crops not only for self consumption but also for earning monetary income, hence they grow crops which are in demand in the nearby urban markets and can easily be marketed. Secondly, in the present time, very few people in the village consume rice beer as majority of them are converted to Christianity and they no longer observe the various rituals and ceremonies as their ancestors. Another reason mentioned by the villagers of Khonoma was that, crops such as millet and job's tears attracts the attentions of many wild animals which comes to eat these crops in the fields and in the process destroys the other crops as well which causes heavy economic losses for them.

The major crops that villagers grow in the present time in Khonoma includes rice, chilli, tomatoes, brinjal, ginger, garlic, pumpkin, cucumber, gourd, yam, lentils, beans, sesame, maize, millet, and job's tears. Thus, there is an increased practice of selective cultivation of crops that have higher economic value and the production of those products with lower economic values is declining over time. This new trend of selective cultivation of cash crops can be said to be as a result of the change in their economic and social lives.

4.4 Awareness About Climate Change

When asked if they have ever heard of what 'Climate Change' means from any source, around 93% of the respondent said that they have heard about the term mostly from television. However, when probed about the level of awareness about climate change, more than half of the respondents (65%) displayed ‘medium’ level of awareness about climate change followed by 27% who had ‘low’ awareness level, and only 8% of the respondents had ‘high’ level of awareness about climate change (Fig. 1).

Climate Change (CC) meant different things to different respondents. The majority of the respondent (57%) believes that CC is a change in the periodicity/pattern of rainfall. Some (27%) felt that CC is reduced rainfall or drought; while some (9%) thought it is increase in temperature. CC is thought to be decline of soil productivity by 4% of the respondent. As many as 7% of respondents had no idea what the term “climate change” meant, with 80% claiming to have noticed change in the climate in the past 30 years preceding the study.

When we asked the respondents to state reasons for CC, responses varied from CC being caused by factories and industries (36.67%) to it being God’s work (6.67%). Respondents who felt that CC was due to increasing use of vehicles are around 32%. Almost 5% of the respondents did not know the reasons for CC (Fig. 2).

However, what is important to note here is that none of the respondent considered shifting cultivation as the cause of climate change. When we raise this issue in the

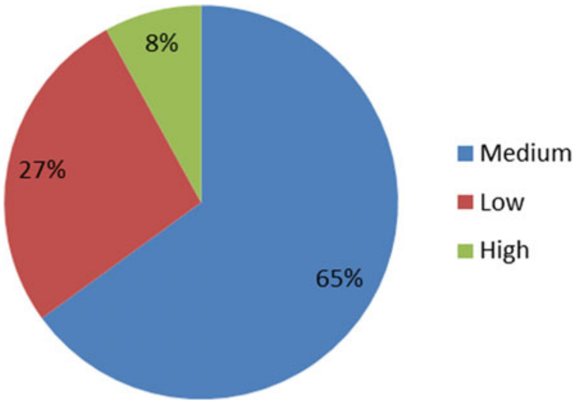

Fig. 1 Level of awareness about climate change. Source: Field Survey (2018)

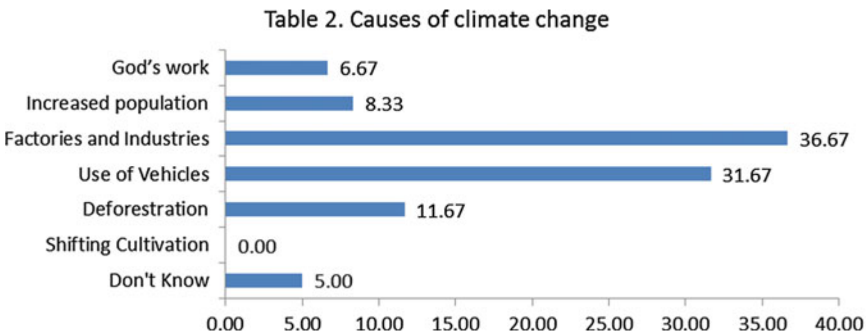

Fig. 2 Causes of climate change. Source: Field Survey (2018)

focused group discussion, they revealed that shifting cultivation in the Khonoma village is distinct and unique in nature. Unlike others, Angami farmers of Khonoma village have perfected the practice of alder based jhum cultivation into a fine art. The alder tree has root nodules which improve soil fertility by fixing atmospheric nitrogen into the soil. It also enhances crop yields and reduces soil erosion. Therefore, shifting cultivation in Khonoma village is rather considered helpful for forest ecosystem.

5 Community Initiative for Sustainability

Shifting cultivation (jhuming) is considered as a bane of development in hill areas. In spite of years of extensive efforts, the level of jhuming has not appreciably come down. This is because the crucial social and human aspects of the problem were not properly appreciated and alternatives offered were not found acceptable by the farmers.

Communitization of Public Institutions and Service (NCPIS) Act, 2002 enlarges the scope of community participation in development and welfare programmes in Nagaland state in areas such as education, health, power, rural water supply, rural tourism, roads, forest, sanitation and rural childcare. This is a partnership between the government and the people through delegation of management responsibilities to the community so that the performance of public utilities improves. Expansion of horticulture in tribal areas to replace *jhumming* is a challenging task and the strategy for this has been worked out carefully. It is extremely important that the tribal population in the region should voluntarily adopt the practice after a demonstration of the gains. Communitization as a developmental strategy which has a significant role in increasing the participation of people in development and historically the systems adopted in Nagaland in this are as important. A clear success story in communitization in rural livelihood systems is the NEC-sponsored North Eastern Community Resource Management Project (NERCORMP) in Assam, Meghalaya and Manipur involving the International Fund for Agricultural Development (IFAD). This is the largest and the most successful rural social livelihood project and the World Bank has shown interest in up-scaling it (NER 2020).

Much successful initiative for development of sustainable shifting agriculture has been undertaken by village councils in different states of north eastern region. One such example is Community initiative in biodiversity conservation in Khonoma village in Nagaland as part of communitisation programme. Jhum cultivation is a centuries-old practice in Khonoma, as in most parts of Northeast India. But developmental activities and population pressure has reduced the cycle to four to five years compared to the earlier cycle of 15–20 years. Because of the reduced cycle, trees like alder are indispensable as they improve soil fertility. Until the 1980s, most households in Khonoma were self-sufficient in food and fulfilled their annual demands from their jhum and paddy fields. Since the late 1990s, the agricultural practice in Khonoma has witnessed a marked shift towards cash crops, a result of numerous programs and schemes introduced by the state government and village council.

The Nagaland Empowerment of People through Economic Development, earlier known as the Nagaland Environmental Protection and Economic Development (NEPED), also encouraged the farmers to increase their income from jhum fields by cultivating cash crops such as pepper, turmeric, ginger, and yam in the fallow land (Chawii 2007).

6 Conclusion

People of Khonoma village depend directly or indirectly on agriculture for their livelihood. Generally, crop farming was revealed to be the common livelihood strategy that supports most households. Though the Khonoma village was traditionally based on subsistence agriculture, the focus of agricultural activity in the present days is shifting towards cash crops. Another notable change is that Khonoma has become a tourist destination with the declaration of Khonoma as the first "Green Village" of India, and the villagers have the alternative means of earning by running home stays and working as tourist guides. There are mainly two types of cultivation method followed in Khonoma Village: Jhum Cultivation and Terrace Cultivation. Though jhum cultivation is rooted in the customs and beliefs of Khonoma people but more and more people are now shifting towards terrace cultivation. This shift has come because of two reasons: firstly, terrace cultivation is less laborious as compared to jhum cultivation; and, secondly, terrace fields are easy to protect from the menace of wild animals. Unlike general perception, none of the respondent in Khonoma village considered jhum cultivation causes deforestation thus contributes to climate change. This is because the farmers of Khonoma uphold a sustainable form of jhum cultivation by planting Alder trees in the fields. Alder is a fast-growing tree species and requires normal soil. Therefore, introduction of alder to jhum fields/sites is highly practicable and which forms a unique agro-forestry system. Alder is one of the nitrogen fixing tree species hence their root nodules contribute in improving soil fertility by fixing atmospheric nitrogen.

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Transitional Peri-urban Landscape and Use of Natural Resource for Livelihoods

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Abstract Peri-urban landscapes are highly dynamic with regard to their land use, social, economic and ecological constructs. Urbanization has its impact outside its boundary and is determined by the types of services and resources provided by the peripheral areas to the city. Increasing pressure on the natural resources to meet the urban and peri-urban needs leads to jeopardized ecosystems which adversely affect the livelihoods of natural resource dependent peri-urban and rural population. This paper intends to look into the general environmental concerns in the context of Indian peri-urban areas. It analyses the pattern of natural resource use for acquiring livelihoods and unsustainable practices in a peri-urban landscape of Guwahati city, northeast India. A cross-sectional analysis, dividing the landscape into three sections with differential urban impacts have shown that, there have been degradation of resources although increase in income from a few natural resources, particularly aquatic resource. The collection of forest resources other than the non-timber forest products (NTFPs) found decreasing in all the three sections of the landscape. The study findings have implications for landscape planning which concludes that the impacts of unplanned urban activities affecting the natural resources in the fringe areas have been realized by the local population. Although expansion of the city has acknowledged the area as eco-sensitive zone, further policy revision is essential to conserve ecosystem and to ensure sustainable and enhanced ecosystem services to cater the needs of both rural and urban population.

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1 Introduction

The health of ecosystems is affected by human interference with advancements in knowledge and technology. Development and environment are inseparable where development is human activities on the environment for the betterment of society. Human beings act upon the environment to achieve inevitable development goals that always affects the natural balance of the environment. The provisioning ecosystem services are those provide goods like food, fodder, fuel wood, water etc. for the sustenance of human and other species. The ecosystem services at different levels of ecosystems are affected by any change triggered by both natural and man-made factors. To acquire maximum economic benefits by human beings, productive landscapes with multifunctional uses are converted into simpler land use form that affects the structure and richness of ecosystems. Sometimes promoting the enhancement of one service leads to diminish other services. Ecosystem services are defined as benefits people obtain from ecosystems (MA 2005), and when natural ecosystems are transformed to promote one service (e.g. agricultural system) that affect functioning of other components and resource flow (e.g. forest cover). The environmental changes have impacts on the ecosystem services, more specifically direct impact on provisional services those provide livelihoods for the natural resource dependent communities like fishing, agriculture, forestry, eco-tourism etc. The ecosystem services framework (ESF) provides explanations for valued aspects of ecosystems/resources consumed by human, directly or indirectly for development, human wellbeing and poverty alleviation, and acknowledges the role of that those services have to provide with healthy ecosystem (Turner and Daily 2008). The provisional services and their changes across temporal and spatial scale illustrate its response to environmental changes and consequent socioeconomic situation of the associated population.

Choosing between conversion of ecosystem and conservation of ecosystem has always been partial; Pearce (2007) stated that decision makers whether individual or government is unable to discount appropriately and provide sufficient support to make conservation rhetoric. An effective definition for ecological sustainability should involve inevitable conversion and robust conservation of ecosystems including biodiversity and habitat conservation, maintenance of ecosystem integrity and livelihood sustainability. Sustainable yield is intrinsically emphasised as physical output, which neglects the underlying processes, human-ecosystem linkages and their sustainability. But a sustainable livelihood is defined as, "*which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the short and long term*"—(Chambers and Conway 1992). According to World Commission on Environment and Development (WCED 1987) definition, "*a livelihood comprises the capabilities, assets and activities required for a means of living.*" Sneddon (2000) emphasized in his research on sustainability in terms of ecology and livelihoods on scale and rapidity of ecological transformations induced by the human species. For the ecosystem-based livelihoods, natural resources that people extract and use for earning their livelihoods are the assets. Thus, any such livelihood can be assessed for its environmental sustainability with respect to the resources used.

Human induced changes in land use land cover enables us to achieve more benefits from the natural resources; on the other hand, such activities damage the natural capacity of the ecosystems in providing other services, like-sustainable food production, maintenance of freshwater resources, regulatory services like climate and air quality (Foley et al. 2005). Urbanization acts as an important driver of change; both biotic and abiotic properties of ecosystems are affected due to urbanization showing it's impacts in the urban area as well as in the surroundings and also in areas far from the city (Grimm 2008). The peri-urban interface can be understood as a social, economic and environmental space where three systems constantly interact: the agricultural system, the urban system and the natural resource system (Allen 2003) and have their own characteristic features. Sometimes the unclear boundary or demarcation of common property resource makes them very vulnerable to such development situation with consequent effects on the livelihoods of the local people. On the other hand, conventional conservation approaches also affect the access right of local population.

Peri-urban area is the most active zone of urbanization that is affected by urban core (Douglas 2012; Frenkel and Ashkenazi 2008; Huang et al. 2011). Iaquinta (2001) refers to peri-urban areas as transitional zone or zone of interaction with both rural and urban activities juxtaposed. The type fringes are also determined by the size and function of the bordering city the services (agricultural produce, forest produce, labour, water, recreational) and resources it is providing towards the city. The linkage between ecosystem services and livelihood is very much apparent in peri-urban-rural landscapes where people are closer to the nature with direct dependency on natural resources. The population in the transitional area tend to shift their subsistence and income earning activities organically associated with natural resources to cash economy.

India's population is largely dependent on natural resources for its livelihoods. To support the life and livelihood of such a huge population safeguarding the environment to provide sufficient ecosystem services for survival and secured livelihoods (fishery, animal husbandry, forestry, small farming etc.) is crucial. Thus, to ensure a sustainable future in those precarious areas of environmental concerns, a framework for sustainability should look at: (a) No declining resources (b) No loss of biodiversity (c) No deterioration of environmental quality and (d) Easy and safe access of local people to the resources.

Approximately 26 million people depend on forest and aquatic resources for their livelihoods. These endemic communities cannot be excluded from the natural system. They have the traditional knowledge to manage and acquire the benefits from the ecosystem and sometimes with no other skill to acquire their livelihoods. However, external pressures for over exploiting the resources as well as environmental quality degradation have made those practices unsustainable. In many parts of the country, these nature-based livelihoods as well as the ecosystems are under threats because of developmental activities like urbanization, mining, industrialization etc.

The central concept of this paper is based on sustainability of resources extracted for livelihoods are dependent on the oscillation of interactive controls within the resilience of the ecosystem. Interactive controls of such peri-urban landscape may be land use, local climate, soil quality, disturbance regime etc. The pattern of availability and use of natural resources will help in maintaining the interactive controls by using laws and regulations to create negative feedbacks between ecosystems and human activities (Chapin et al. 1996). The definition of sustainability for the urpose of this research involves non-degrading resources and economic development of natural resource dependent communities. The objectives of the paper are: (1) To discuss the issues pertaining to peri-urban interface of India based on previous studies (2) To assess the pattern of aquatic and forest resource use in last three decades across the landscape (3) to examine the unsustainable practices prevalent in the landscape that affect the natural resource base and subsequent livelihood assets.

2 Methodology

The association between ecosystem and human is prominent in rural and peri-urban landscapes where direct dependency on natural resources is higher than urban areas. Analysis of livelihoods distribution and its changing pattern give an overall account of the changing landscape as the recent developments in livelihood assessment frameworks are multidimensional, particularly assets (DFID 1999; FAO/ILO 2009) and landscape (Sheil et al. 2002; WWF 2009) approaches. Livelihood frameworks have been found as an effective construct for decentralized natural resource management. Thus, assessing natural resource as livelihood asset (e.g.- asset model, asset vulnerability framework) in the vulnerable peri-urban interface is becoming a common tool. In this paper, assessment of two natural assets of livelihoods- forest and aquatic resources have been discussed. The present study is based on primary data collected through household survey conducting empirical study in the rural-urban transect by selecting the households. The information collected following the questionnaire survey was cross verified through actual investigations in field, e.g.—for example various kind of resource collection from nature (forests and aquatic). Fish catching points were visited to estimate the fish caught per day for a few selected households. Assessment of income from different sources were verified by visiting local markets. Fuelwood and other forest products are usually collected and carried on walk load or bicycle load through a few definite routes connecting the forest and villages. A random survey of 10–12 h on junctions of those routes were carried out to authenticate the data on forest resources.

The mapping for delineating study region was done using the base map available at development block with participatory mapping exercise to demarcate the study landscape. Spatial extent of interaction with natural resources and road networks has been taken as the criteria for delineation of the landscape. To study the landscape dynamics three decades period was taken for detailed understanding. To see the impact of urbanization the area is divided into 3 parts according to the extent of

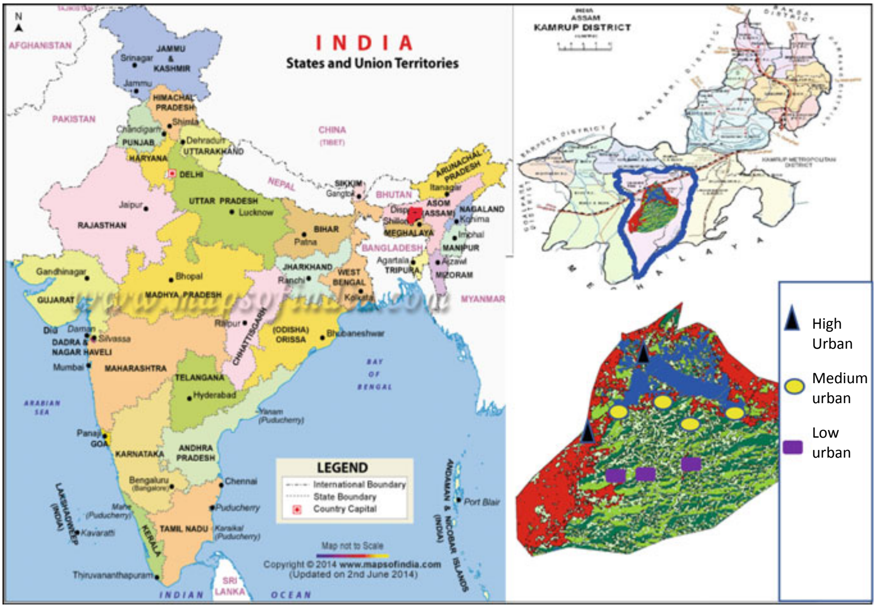

Fig. 1 Location of study area and selected villages for household survey

urbanization namely, urban (high), peri-urban (moderate) and rural (low) (Fig. 1). The criteria considered for delineating the three urban zones were based on distance from the city core, population density, availability of various facilities, accessibility (for what), pattern of occupation.

The methodological framework followed to conduct this research is depicted in Fig. 2. The six settlements selected on the basis of natural resource dependency have approximately 500 households with complete dependency on natural resources for their livelihoods. In-depth household survey was conducted for such 248 households (38.7% from high, 26.6% from medium and 34.7% from low urban impact zone) using structured questionnaire was done, provided data that adds a useful temporal dimension and picks up seasonal changes in livelihood patterns (Malleson et al. 2008). A stratified sample has been chosen from the census village households. Households were selected on the basis of their dependency on natural resources, being natural resource dependency the primary focus of the study. Households have been covered in all the three urban impact areas as mentioned. Questions were structured to acquire information on pattern or livelihood change in three decades, income generated from different sources of livelihoods, quantity of natural resource extracted along with scioeconomic profile of the households. Detailed information has been collected on three different types of natural resources viz.—fishery, forest and agriculture.

The data collected through households' socioecological survey which are verified, and tabulated using MS-excel. All types of natural resources used by the studied

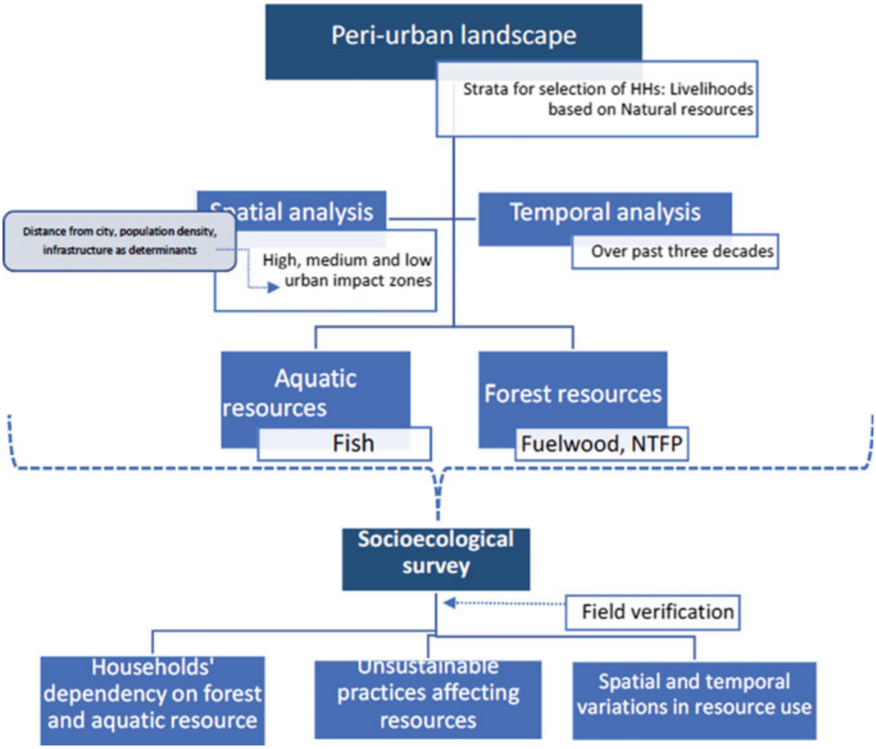

Fig. 2 Methodological flowchart of the study

households are listed and contribution towards their livelihoods are estimated. Quantified data are verified and further used for analysis to present the temporal and spatial pattern of aquatic and forest resource use.

3 Study Area and Climate

The study area is located at the periphery of Guwahati city, Assam, a north-eastern state of India (Figure 1). The selected landscape has a spread of 91.33 sqkm. The area extends from 26° 2′53.41″ N to 26° 8′36.07″ N and 91°36′15.68″E to 91°39′58.60″ E. The area is comprised of the villages, protected forests, agricultural land and an ox-bow lake (Beel). Being geographically constrained, the city of Guwahati has the only scope to southwestern direction which has been evident in future city planning from Guwahati Master Plan 2025 (GMDA 2009). The municipal limit of the city increased from 7.68 km^2 in 1951 to 14 km^2. in 1961, which further increased to 216.79 km^2 in 1991. In the Comprehensive Master Plan-2025 (GMDA 2009), presently under preparation, the existing Guwahati Metropolitan Area is proposed to increase by

66 km^2. Availability and easy accessibility of land in the city surrounding is a major enabling factor for city expansion creating a broader transitional peri-urban area. Considering the prospect of urban growth and existence of ecologically sensitive features, the Rani-Deepor Beel-Garbhanga landscape has been selected as the study area. There has been immense filling up of agricultural land and several water bodies to give place to concrete development. The Deepor Beel of Assam (Kamrup District) is a Wetland of International Importance declared in Ramsar Convention. Due to variation in vegetation structures, the forest has been divided into two forest ranges -the Garbhanga range (18,861 ha) and the Rani range (4370 ha). The forest reserve is also continuous with the Jarasal-Kwasing Reserve, Nakhalliyang Wildlife Sanctuary and Jirang State Forest of the neighbouring state of Meghalaya. The climate of the area is characterised by high humidity (80–90% maximum recorded) and moderate temperature. Humid tropical climate of the region has a prolonged monsoon of 5 months (May to September) and a relatively cool and dry winter. The average minimum and maximum temperature of the area are 10.6 °C and 32 °C respectively. The landscape receives heavy rainfall of 300–450 cm.

The city of Guwahati has a better urban poverty ratio (9.09% urban poor) as compared to urban India's percentage of 13.7, although the Assam has a higher urban poverty with 20%. But the selected landscape has a very low per capita annual income (Rs. 11,585). 18.13% of the total population is scheduled tribe; that part of the population belongs towards the rural gradient of the landscape and the tribal communities are in the villages of the hilly region, which belong to Rani Gram Panchayat and Azara Gram Panchayat, which are under the low, or no urbanization region of the landscape. Scheduled caste population of the area is accounted for 10.37% and they live in the plain area. In the selected study landscape, the population growth from 1991 to 2001 is 29.6% and from 2001 to 2011 is 17.8% in comparison to the same for the state of Assam 18.9 and 16.9 respectively. Table 1 depicts that the percentage of cultivators have decreased from 32.65% in 1991 to 47.77% in 2011;

Table 1 General description of the study landscape

Socioeconomic parameters	Rani-Kamrup Metro		Selected settlements
Year	1991	2011	2011
Total area in Ha	7859		2050
Total HH	5880	14,642	3449
Total Population	34,054	64,247	15,015
Population density (person/hectare)	4.33	8.17	7.32
Literacy %	57.71	78.76	78.91
Total worker	8090	19,024	5526
% of cultivator	32.65	11.44	4.6
% of agricultural labourer	30.44	47.77	8.38
% of industrial (HH) worker	2.14	5.2	5.05

Sources District Census Handbook and Village Directory, Census of India, GoI (1991, 2001, 2011) whereas there has been an increase in agricultural labourers. The selected settlements have 4.6% of its total population involved in doing agriculture. More than 72% of the studied population belongs to schedule tribe; whereas 100% of the low urban area sample is schedule tribe. 77% of the studied population is below poverty level. Percentage of below poverty level households in villages of medium urban area is low in comparison to rest of the villages.

4 Results and Discussion

4.1 Peri-urban-Rural Interface in Indian Context

(a) Unplanned growth and dynamic land use change

Ravetz et al. (2013) explains peri-urbanization in terms of differential industrialization; in developed and old industrial countries, peri-urban zone functions as social, economic and spatial change, whereas in developing countries it is a zone of chaotic urbanization leading to sprawl. It has a higher dependence on rural activities for wealth and employment (in agriculture, mining and fisheries) in developing countries than developed countries (Lynch 2004), thereby exerting a greater pressure on the biophysical landscape. Simon (2008) analysed the key peri-urban interface issues in poor and middle-income countries pertaining to both biophysical and socioeconomic landscape change. The major concerns listed include the rate and scale of land use and land cover change, loss of agricultural land, intensive market-oriented farming of high value crops, unsustainable use and depletion of both renewable and non-renewable resources, detrimental health and environmental impacts of wastes, particularly landfills.

India's urban development is not uniform throughout the states; half of the urban population is concentrated in six developed states (Kundu 2011). Massive peri-urbanization happens when a country approaches towards the advance stages of development. India has experienced early suburbanization and stagnancy in metropolitan areas is partially due to the push of firms and workforce out of the city core, which is facilitated by land management practices (World Bank 2013) and environmental policy. As a result, there is proliferation of industries, expansion of urban areas with conversion of agricultural land (Pandey and Seto 2015; Moghadam and Helbich 2013; Mallupattu et al. 2013; Fazal 2000) and change in the livelihood patterns of peri-urban communities (Narain 2009). In Indian context, before the era of extensive LULC research, detailed studies were conducted with special reference to the urban growth or economic development. In the study landscape the land use land cover change has been found as extensive where percentage of area under all the natural land use land cover classes have decreased from 2001 to 2011 whereas the built-up land has increased from 9 to 25% during this period (Goswami et al. 2018).

Land use land cover conversion and allied impacts have been seen as the major factor causing shift in natural resource based livelihoods.

(b) Disposal of residue and assimilative capacity

Research shows (Purushothaman et al. 2016) that Indian peri-urban areas indicate a certain gradient from rural to urban only in case of indicators pertaining to environmental externalities. The controlling factors for peri-urbanization and rural-urban linkages vary from one to another peri-urban area, which set the mandate to assess the diversified sustainability concerns in peri-urban landscapes. The rural-urban fringe in India is due to increasing impact of the urban area on nearby villages, whereas in developed countries, it is due to diffusion of population. The realization of link between urbanization and environment has been emerged in last three decades as a major concern (Maiti and Agrawal 2005) as modern cities have grown in a haphazard and unplanned manner due to fast industrialization (Jaysawal and Saha 2014).

Shaw (2005) discussed the environmental dimension of spreading urbanization. The findings included problem of increased environmental vulnerability due to solid wastes in the peri-urban areas, which can be managed by improved governance and local initiatives. Another important environmental concern identified is the shifting of polluting manufacturing industries to the periphery of the cities. This shift is encouraged by available low-cost land, accessibility to unorganized workforce, weak implementation of environmental regulations due to lack of awareness in the city periphery (Kundu 2011). Growing environmental concerns generally lead to shifting of large and polluting industries outside the city limit, thereby concentrating industrial activities and settlements of working population as well in the periphery.

(c) Lack of physical infrastructure

The transitional peri-urban areas have been recognized in spatial and economic terms in Indian context with regard to commodity flow, housing, peri-urban agriculture and pollution in recent years. The Tier-1 cities in India have already faced environmental problems, which are evident from poor assimilative capacity (higher levels of pollutants), supportive capacity and lack of basic infrastructures (Ramachandra and Aithal 2013); those have been able to attract attention for appropriate environmental planning and management. On the other hand, high level of urbanization has been noticed in economically backward states too (Kundu 2011). Indian peri-urban areas have weak basic services, and metropolitan peripheries fare poorly on access and quality (World Bank 2013) and failing to generate any of the gains in income, happiness, and mobility that the US, Brazil and China have experienced (Chauvin et al. 2017). The migrant workers are also able to find an affordable shelter in the peripheral zone of the city and along with a job in the industries and can avail a less troublesome commute to the workplace even if it is in the city core (Kundu et al. 2002). Thus, sprawling starts in the periphery which is not supported by adequate infrastructure because of the sudden demand or its non-inclusion in urban administration.

The present study has also reported the inadequacy in basic services and infrastructure. The major drinking water sources in all the studied villages are open well and hand pumps since 1990s. Only a few households from the low and medium urban influence area have access to piped water supply, which is provided under National Rural Drinking Water Supply Mission.

Open defecation is still highly prevalent in the landscape; instead of governments' programme like Total Sanitation Campaign, Swacch Bharat low urban impact villages, majority of people do not have access to toilet. In all the three sections of the landscape, the households have a gradual increase in access to toilet over the decades, yet the present percentage of households accessing sanitation facility is only 58%. The same is distributed as 70%, 75% and 23% in high, medium and low urban influence areas respectively. It is much lower than the households having toilets within the premises for the Guwahati Municipal Development Area, which is more than 85%. The studied households use fuelwood and LPG the most as their cooking fuel with an exception of seven families using kerosene and biogas in the last two decades. In the present days and the last decade, the households are using LPG, fuelwood and a combination of LPG and fuelwood. Fuelwood is used by 42% and 40% in high and medium urban impact areas respectively. Combination of LPG and fuelwood is used in medium and high urban impact areas as 30% and 33%.

(d) Agriculture and urban resource flow

Bunting (2007), Johanna et al. (2009), Agrawal et al. (2003), Brook et al. (2001) and others have focused on studies related to peri-urban agriculture in India with special reference to waste water use in agriculture and aquaculture, pollutant residues in food products, impact of air pollution, food security and livelihood enhancement in peri-urban areas of various cities in India. Study in fringe areas of Delhi reveals that although the villagers have been exposed to prolonged urban influences, land continues to be an integral part of their lives specially in terms of acquiring their livelihoods (Mallik and Sen 2011). The peri-urban areas of sprawling cities experience significant land transformation, due to expansion of the urban core contained within their boundaries (Dutta 2012). The studies also reveal different processes and levels of urban influences that manifest significant social impact with prominent temporal variation. The pressure of urbanization has been felt more by agricultural land than natural land. This may be because of the cost of conversion in terms of clearing of forests, filling up of water bodies and so on. Conversion of natural land is higher than that of agricultural land because of the drive to conserve natural areas (Kumar 2009) and further affect on land ownership, property rights regime and land tenure (Wehrmann 2008).

Urbanization produces a variety of unprecedented and intense "experimental manipulations," potentially undermine the capacity of ecosystem to sustain production and maintain the resources (Foley et al. 2005). This leads to intensive use of resources to serve the growing urban demand, for instance, small area of land would be used for intensive cultivation for crops with market demand instead of subsistence farming. Studies demonstrate farmers are dependent and threatened by the dynamics of broader urban economy (Friedberg 2001).

Decrease in households' landholdings, diversification of livelihoods and decrease in income contribution from natural resources have been evident in the study area. Previous analysis shows 50% of total land area of the landscape was converted to agricultural (20.15%) and barren land (30.33%) in the first decade of the study (1991–2001); again in the later decade (2001–2011), conversion from barren land to agricultural and built-up classes accounts more than 21% (Goswami et al. 2018). The agricultural practices have been driven by market demands to feed the growing urban population, thereby replacing the traditional crop varieties and subsistence village farming with cash crops. Despite of increase in agricultural land area and market demand, the contribution from agricultural production towards household income has not increased. Agricultural livelihood as primary source of income for the households has decreased among the surveyed population in the landscape, i.e. from 22% in 1990s to 7%in 2010s.

(e) Undefined boundary and governance

The doomed state of environment in peri-urban areas is explained as a result of official neglect and non-recognition to award urban civic status by Saxena and Sharma (2015). Marshal and Randhawa (2014) attribute the poor state of peri-urban areas to institutional obscurity, unplanned growth, lack of infrastructure and environmental degradation. The World Bank report (Urbanization Beyond Municipal Boundary 2013) looks at the role of public policy in potential productivity gains of urbanization with an emphasis on land management policy. It suggests that integrated improvement of land policy, infrastructure and connectivity can help in obtaining optimum benefits from the expanding urban areas in India.

In Indian context, the assumption is that the peri-urban areas formation is related to 'push factors', such as a deteriorating environment, creating a strong influence on these areas beyond the traditional city limits (Thirumurthy 2005). Peri-urban boundary is forever shifting, followed by extending urban areas engulfing the interface in route (Dutta 2012), affect social systems and agricultural land of rural communities near urban agglomerations (Bryant 1992; Antrop 2000). The fringe villages of urban areas try to retain their characteristics, yet, react to urban situation by altering their socio-ecological and cultural structures.

Ramachandra (2012), Ramachandra and Aithal (2013), Reddy and Reddy (2007), Goel (2011), Hackenbroch and Woiwode (2016), Vij and Narain (2016), Dupont (2007), Narain and Nischal (2007), Narain (2009) and Dutta (2012) studied peri-urban areas in different Indian context. Those studies include the spatio-temporal dynamics of urbanizing landscape, top down policy and planning focus, population dynamics, urban edge expansion and envelopment at the cost of permanent crops and pastures, material and service flow livelihood enhancement etc. The available studies reiterate the need of integration of various sectors and advocate for bottom up approach for urban expansion planning where the opinions of various stakeholders would be accounted.

5 Aquatic Resource and Livelihoods

Wetlands are among the most productive ecosystems. Wetlands are essential for the numerous benefits or "ecosystem services" that they provide, ranging from freshwater supply, food and building materials and biodiversity, to flood control, groundwater recharge and climate change mitigation. Among the 14 villages surrounding the wetland, more than 22.63% people depends on wetland resources for their livelihoods, around 50% is dependent on wetland for fodder and cattle grazing, and 17.3% partially depends on the wetland for their livelihoods (Aranyak 2003). It left out only 10% people of those villages who are not dependent on natural resources of the wetland for their livelihoods. The wetland is enriched with more than 60 fish species among which eight are listed as endangered. The wetland also serves as a major breeding ground that supplies fish to all nearby waterbodies. The total economic return from the wetland in terms of biodiversity goods is more than Rs. 20 crore per annum (Saikia and Saikia 2011).

Wetlands come under threat from industrial effluent discharge, sewage disposal, solid waste dumping, invasive species and encroachments. Water Hyacinth is a widespread alien species that cause significant ecological damage, and growth is promoted by nutrients supplied by municipal sewage and agricultural runoff. It has also potential to be economically important if it is harvested. As a result of sewage discharge and growth of aquatic weeds like water hyacinth, the lake has been undergoing a speedy eutrophication process which consequently shallowing up the lake bed converting water spread area to land area. There have been instances of land mafia who are trying to grab the land in the low-lying areas and filling them with soil to use those for development. Border security forces housing complex, mother Teresa hospital, Artfed Industrial complex, etc. is constructed in the swampy area of the lake. A number of temporary farmhouses, brick kilns and other commercial establishments have threatened the existence of natural resources; allotment of government land to private parties for development has encouraged this unwanted change (Mondal and Sharma 2011). With the progress of time during the last three decades, the wetland has been fragmented by detachment from each other due to vegetation growth, encroachment etc.

Deepor beel provides direct as well as indirect benefits to 14 villages and more than 1200 families are directly dependent on fishing and collection of herbaceous plants (Saikia et al. 2014). The survey shows the villages close to the city those are predominantly inhabited by scheduled class people have ancestral right (60.6%) over the wetland to do fishing (Table 2). Among them, 23.44% holds formal permits to do fishing in the lake. The community from medium urban region mostly go for community fishing during festivals although it has been banned under the Wildlife (Protection) Act, 1972, in 2009 by district administration. The high urban villages are most likely to be affected by the deterioration of the lake ecosystem because of urban activities. The low urban community goes for fishing mostly for domestic consumption (74.44%) which is also not regular. They comprehend domestic sewage

Table 2 Pattern of fishing rights held by the families of the study area

	% of HHs with different types of fishing rights			
	Ancestral	Ancestral with license	Only community fishing	Domestic consumption
High urban	37.19	23.44	3.13	36.25
Medium urban	12.5	0	54.17	33.33
Low urban	21.74	0	3.82	74.44

(37%) and industrial waste (28%) as top ranked threats to the lake that is affecting the fish diversity.

The decrease in fish diversity and production has been evident from the research. Among the fisherman community, annual fish caught has been decreasing (Table 3) despite of increased demand. Studies by Hazarika (2013) and with inputs from Assam Fishery Development Corporation show that the fish yield of the wetland has come down drastically from 163.8 tonnes in 1991 to 47.3 tonnes in 2001 and to 37.5 tonnes in 2011. Regulation of access to the lake due to declaration of protected area has been stated as by the majority of the people, which is affecting their fishing livelihood across all the urban impact villages. Restriction of season and net size, and impediments by land mafia follow that in high urban areas that create conflicts and hamper their daily livelihood. On the other hand, studies state the decrease in fish diversity is caused by intensive fishing and deteriorating water quality due to agricultural run-off with fertilizers and pesticides (Goswami and Kalita 2012; Saikia and Saikia 2011).

Table 3 depicts that the production of fish is decreasing over the last three decades; whereas, the income of the fisherman households from the wetland has been increased. The list prepared from the fish vending women (a sample of 28) on the disappearing fish species shows that a total of 7 species of fish (*Channa barca, Botia dorio, Danio* spp., *Ompok pabho*, *Cirrhinus reba)* can seldom be seen in the present decade. The average income from fish has drastically shot up from 1990s

Table 3 Quantification of average fish catch by fishing households (as primary and secondary livelihoods) and corresponding average income over the three decades

Urban impact gradient	1990s		2000s		2010s	
	Income (in Rs) from Fish/HHs/year	Fish caught in kg /HH/year	Income (in Rs) from Fish/HHs/year	Fish caught in kg /HH/year	Income (in Rs) from Fish/HHs/year	Fish caught in kg /HH/year
High urban	16,651	1110.09	51,100	1022	189,800	949
Medium urban	9533	635.59	19,162	425.83	124,100	620.5
Low urban	0	0	17,520	438	43,800	292

to the present decade, which is highest among the fishermen of high urban area in present decade, Rs. 189,800 per annum. The average annual household budget of fisherman households of Deepor Beel area was Rs. 2662 during 1990s (Kakati 1999) with fishing as the primary livelihood options. During that period, the other small subsidiary income sources of fisherman households were small business, daily wage labour, rickshaw pulling which varies from Rs. 700–1200 and the agricultural income was below Rs. 1000 per annum. It was noticed that the required expenditure i.e. basic necessity was much more (30%) than their actual income level. However, the present study shows, more than 73% of households with fishing as primary livelihoods earn more than Rs. 200 per day which even reaches Rs. 1000 on a good fishing day. The market price of most commercial fishes during 1990s was Rs. 12–14 per kg (Assam Fishery Development Corporation), whereas the same in the present year reaches more than Rs. 1500 per kg (The Sentinel, 16th January, 2016 stated that Rs. 10,000 for 4–6 kg of fish).

Another auxiliary income from the lake for fishermen households comes as fish vending; mostly women either buy the fish from other fisherman or get it from their family members (husband or son) who go for fishing. They sell fish for around Rs. 1200–1500 and make a profit of Rs. 200–300. Six of the respondents told that they used to go for door-to-door selling of fish earlier in 1990s, even travelled to the city centre. However, in recent years they do not have to go to other areas as demand for fish in this market is very good because of the growth in that area, as well as the increased number of vehicles on the National highway passing through the market who stop for buying fresh fish. No fish is left unsold at the end of the day as told by all the respondents. They do it for 20–25 days/month. Most of the women do save Rs. 20–25 per day from their earnings, mostly in chit funds.

6 Forest Resources and Livelihoods

The threats to forested landscape are ever increasing for the needs of agrarian expansion that only intensified with time. Forest tracts in the foothills areas are diminishing due to increased harvest of timber and fuelwood (Sharma 2017), agrarian practices or encroachments. The forests are closely linked with domestic sector, agriculture, animal husbandry and provide food, fodder, leaf litter for agriculture and timber, etc. (Nautiyal 1998). Though there is a huge scope for rural non-farm sector as a whole in Assam; poverty, lack of opportunities etc. have been augmenting the use of forest resources for energy and livelihoods (Billand et al. 2012). Because of the economic backwardness in the areas, the opportunity to go for an alternative livelihood is inadequate and that makes them more dependent on forests.

Apart from revenue earning, forest provide source of sustenance to poor people especially those living in the hills and in the vicinity of forest. Although forests as a source of state revenue contribute only 0.30% of the total State revenue earning, it remains the fact that forests provide direct economic support to about more than 15 lakhs people in the rural areas of Assam (Tamuli and Choudhury 2009). Changes in forested landscape cannot be assigned to single factor. A multitude of factors act at various scales starting from shifting cultivation, smallholders' agricultural expansion, grazing, logging to large-scale clearance for development of infrastructure causing forest fragmentation and thus loss of forest.

Rani Garbhanga Reserved Forest is located at the southern fringe of Guwahati city with a cover of 227 km^2 and partly comes under my study area. Topographically, this Reserved Forest represents an ecotone in the transition zone between Meghalaya Plateau and Assam Valley consisted of different habitat types embedded in the hilly-forested terrain with perennial and seasonal streams.

The people living in peri-urban area use fuel wood, kerosene, LPG and combination of those as cooking fuel. The high urban people go to the forests towards medium and low urban impact areas for collecting fuelwood. The studied households use fuelwood and LPG the most as their cooking fuel. The study shows only 22% households are not using fuelwood in high urban areas and 16% in low urban impact villages. In relation to the adoption of LPG as cooking fuel, a trend showing decrease in fuelwood collection is expected. However, it is not apparent from the survey results. Thus, we can see that the majority of the people are still dependent on forest for their domestic demand. In lower urban impact area, villages adjacent to the forest collect fuel wood for selling as they are using LPG as cooking fuel.

The control of the forest area is under the State Forest Department. However, it has been reported that illegal timber logging and activity of timber mafia have been going on at large scale in Rani-garbhanga Reserved Forest area (The Assam Tribune 2012). It is encouraged by the illegal sawmills along Assam-Meghalaya border. The spillover of urban population has resulted in increased residential and commercial built-up area in the northern part of the forest, which has also promoted other infrastructure like road development (Saikia 2013).

Only in medium urban area, the increased LPG use has an impact on fuelwood collection, showing a decreasing trend in quantity of fuelwood collected (Figure 3). The quantity of fuelwood collection by household shows a negative correlation ($r = 0.8$) with the livelihood diversification index which reveals that the households who are more dependent on forest resources have less diversification of their livelihoods. Nevertheless, the adoption of LPG is quite significant the landscape, it is not able to replace the fuelwood collection at the same rate. Specially in the low urban area.

Although the collection of timber is banned in the forest area, there are households who have been collecting timber from the reserved forest. The number of timber collecting households have been declining, yet a 10.5% of sampled population in low urban area is collecting timbers in present decade (Table 4), and it is actually expected to be higher. Period and frequency of wild vegetable collection varies from village to village and household to household. Cane and bamboo are two major sources of income for the forest dependent communities. In Assam, culturally diverse ethnic societies close to nature have developed many eco-cultural landscapes and those linkages can be seen as effective tool for conservation management. Bamboo (*D. Hamiltoni*) is a very important NTFP of the landscape that provides subsistence and

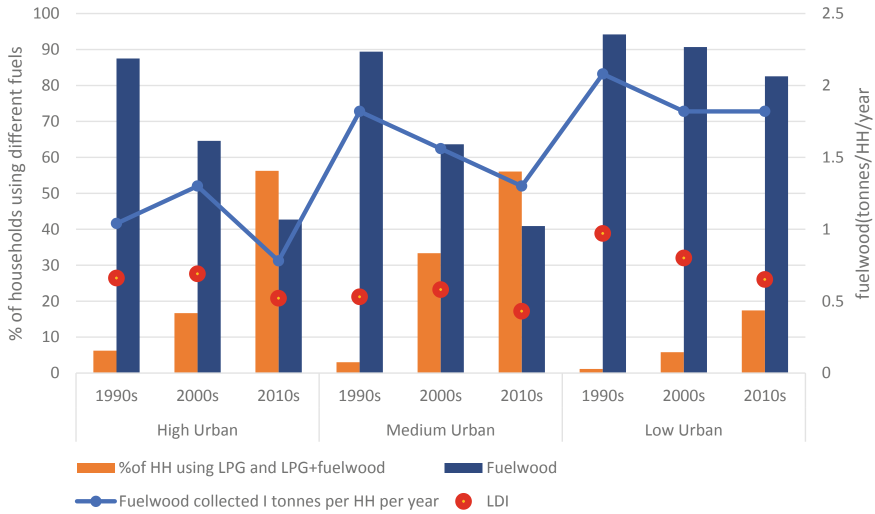

Fig. 3 Pattern of fuelwood use with relation to adoption of cooking fuel and livelihood diversification

livelihoods security to the local village community and is a part of their traditional attributes.

Forest dwellers are the first legislative handle to assertion of tenure rights and addresses important livelihood security issues (Forest Right Act 2006). For acquiring their livelihoods, forest dwelling community (Sattargaon) has been given forest land on lease for cultivation. However, felling any tree or cutting or dragging any timber from Reserved Forest is prohibited (The Indian Forest Act 1927). It has been reported that people from the villages in plains come to the forest and do large-scale logging; though it has not affected their livelihoods, they do not want to allow them to pursue such activities. Female groups of the village have been trying to stop the outsiders from felling trees. It has led to conflicts among communities in the society. They sell the fuelwood twice in a week in the market at Sajjanpara. They have to go to the interior of the forest for collection of different types of cane.

Collection of NTFP by forest dwellers is either for domestic consumption or selling those in local market for getting their subsistence needs. Unlike central or eastern India, forest dwellers in Assam do not extract NTFP as the main source of sustenance. The forest dwellers in the region are mainly marginal agricultural families with some dependence on forest products for their sustenance. Ideally, degradation of agricultural land for various reasons including urbanization may lead the forest dwellers or people close to forest to higher dependence on forest resources. However, in the studied landscape, it shows no increase in the quantity of NTFP collected by households.

Table 4 Forest resource collection in the region

Forest resources	High Urban			Medium Urban			Low Urban		
	1990s	2000s	2010s	1990s	2000s	2010s	1990s	2000s	2010s
% of HHs doing commercial collection of									
1. Timber	7	4.5	2.7	11.3	8.9	7.3	15.4	11.2	10.5
2. Fuel wood	35.6	28.9	21.6	33.6	31.5	30.1	35.7	35.2	34.9
3. Cane + bamboo	30.8	28.4	30.5	26.6	25.7	29.8	33.3	29.5	28.7
4. NTFP + medicinal + others	26.6	38.2	45.2	28.5	33.9	32.8	15.6	24.1	25.9
Fuelwood collection Kg per HH per week									
Fuelwood	20	25	15	35	30	25	40	35	35
NTFP Collected in Kg per year per household									
1. Tuber/roots	245		200	260		250	300		280
2. Stems/leaves	35		30	30		25	40		35
3. fruits/flowers	65		55	70		60	60		55
4. Medicinal plants	12		7	10		10	15		10

7 Unsustainable Practices in the Landscape

Peri-urban areas are more environmentally unstable than their adjacent rural and urban areas because of transitional nature. Changing physical and socioeconomic landscape has led the community to adopt practices to extract more resources exerting tremendous pressure on ecosystem. Apart from community's action on natural resources, ill-planning for urban expansion and waste disposal have threatened the sustainability of the resources. Shrinking of the wetland area, deforestation, decline in cultivable area etc. have not only affected the ecosystem balance but also the indigenous population living in the city periphery. Agricultural practices of the villages have also been affected due to land degradation. The growth of urban areas and developmental activities has been exerting pressure on the ecosystem. As discussed in the previous chapters, majority of the biological goods of the landscape has been gradually depleting due to increased human interference. The water quality of the wetland is threatened by sewage and solid waste disposal, excessive fishing, hunting of water birds, agricultural runoff and infestation by aquatic weeds. The degradation in the wetland part of the landscape is primarily caused by encroachment and waste dumping. Urban sprawling has carried its impact towards the fringe areas through changes in land use land cover and consequent ecosystem services showing a decreasing impact gradient from the core of the city. The significant changes the villagers have noticed about the landscape are presented in Fig. 4.

The people in all the segments of the landscape ranked pollution as the most protuberant consequence of urbanization which is followed by hill cutting. Hill cutting and quarrying is an activity prevalent in low and medium urban areas, yet the impacts of this is more apprehended by high urban areas as it has been causing siltation in the lake and flooding. Road accidents (both man and animal) has been seen as one of the major adverse impact of urban development in the central part of the landscape

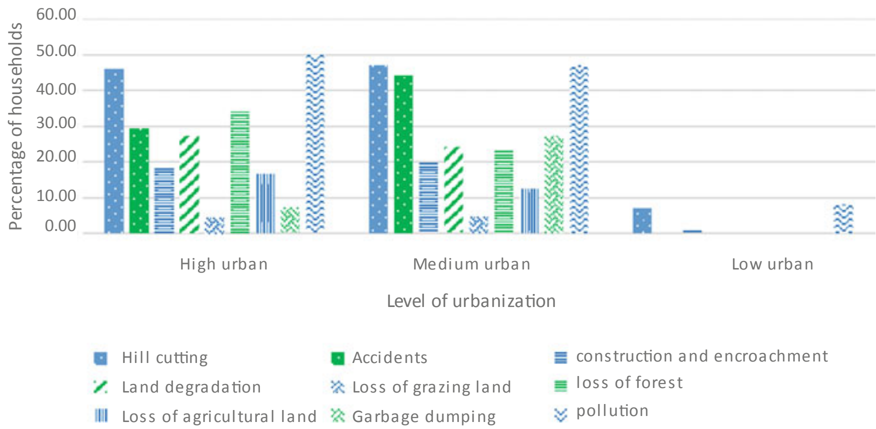

Fig. 4 Response on impact of Urbanization across the landscape

Table 5 Summary of major factors affecting the landscape as reported by community

Urban expansion	Infrastructures	Roads connecting the city and Airport, Railways crisscrossing the wetland
	Land	Encroachment in lake and forest areas, allotment of government land to private parties
	Residue disposal	Both municipal solid waste and untreated sewage disposal into the lake and surrounding areas
	Industry	Industrial development within the periphery of the lake, brick kiln degrading the land around it
Unsustainable resource use practices	Biodiversity	Hunting, trapping and killing of wild birds and mammals
	Hills	Commercial scale forest exploitation, quarrying, soil compaction
	Fishery	Unplanned fishing practice (without controlling mesh size and using water pump, etc.)

Source: Goswami et al. (2018)

where a new road has been constructed (in 2000s) to connect the city and the airport (Table 5).

Along with fulfilling the need of indigenous communities and urban population, the natural resources of the landscape have to provide goods and services towards a huge migratory and floating population. People displaced due to flood and land erosion are also contributing towards this increasing pressure. In absence of industrialization and skill, dependency on natural resources is not significantly reducing despite of inclusion of villages from the landscape in urban limit. Many forest dwellers are new to the landscape who have settled down there either because of displacement from their native place or in search of easier livelihood opportunity. The ongoing land rights movement started in 2002 by community organizations including *Krishak Mukti Sangram Samiti* in other districts of Assam has found reverberation in the city and surrounding areas of Guwahati which consists of a number of reserved forest areas.

Dwindling forest cover, massive habitat destruction (Barua 2008; Saikia 2013) and animal killing in contiguous forests of Rani-Garbhanga in Assam and Meghalaya have caused shifting of animals from the hills to the plain part of the landscape (Mitra and Bezbaruah 2014). Human population amidst the forest is also facing the problem of livelihood support for decreasing production on the hill slopes where they traditionally practiced shifting cultivation as well as forest resource gathering. Some of the forest villagers shifted to the valley areas, and more particularly to Rain

Forest area. Natun Satargaon is one of such villages which shifted about 6 km from Garbhanga Reserved forest to Rani Reserved forest.

8 Conclusion

The change in peri-urban landscape is inevitable; therefore, the change in natural resource. This cross-sectional study provides an overview of how the studied landscape is changing with relation to urban impact over time. Results have implications for development planners in the peri-urban landscape, where the dependence on forest and the lake for livelihoods are significant among the studied households. Nevertheless, the increased demand for natural resources from the city has propelled increase in income, but the quantity harvested has been decreasing in all the three sections of the landscape, irrespective of harvest for domestic or commercial purpose. Unplanned developmental activities and degradation of land and water resources have immensely put pressure on the studied resources. Adverse consequences in the socio-ecological systems like increasing man-animal conflicts, conflicts among the communities over resources etc. are apparent in the landscape. The interactive controls like land and water qualities have to be maintained for enhancing natural livelihood assets. Although expansion of the city has acknowledged the area as eco-sensitive zone, further policy revision is essential to conserve ecosystem and to ensure sustainable and enhanced ecosystem services to cater the needs of both rural and urban population. Formulation of new policies or changes in the existing to encourage positive interplay between diversifying livelihood strategies and natural resource management and SLM practices could help in the attempt to achieve a sustainable landscape.

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Emerging Technology Intervention Model of Core Support for Inclusive Rural Growth: Social–Economic–Ecological Interface Building Through Innovative Scalable Solutions and Effective Delivery Mechanism

Sunil K. Agarwal

Abstract Present paper highlights through case studies about the field level experiences in implementing unique program of Core Support under TARA scheme of Department of Science and Technology (DST) to address the emerging challenges of inclusive growth at the grassroots level. Paper discusses about possible adaptation strategies, various factors and actors involved in effective governance and towards improved ecosystem services and rural livelihoods to reduce vulnerabilities with scalable and affordable technological interventions for rural growth. Paper also discusses and analyzes cutting-edge practices in providing affordable technology access including innovative delivery mechanism with local institutional arrangements at the grassroots level though a network of S&T-NGOs. Analysis of their work for adaptive Research and Development (R&D) on efficient use of resources and in renewable energy and environment sector evidently shows that as a process mechanism it is important to strengthen local knowledge, innovation capacity, and practices within social and ecological systems for successful adoption of innovations under rural settings. It clearly suggests that DST's **Core Support Model for S&T-NGOs** evolved in India provide excellent opportunities for inclusive innovations to make a more meaningful contribution to society through technology driven developmental initiatives. Paper further suggests that policy level interventions are needed to have more such S&T-NGOs across the country with enabling environment to crate vibrant ecosystem for visible transformation in rural areas through scalable technological solutions. This needs to be promoted for technology led growth strategies based on diversification in rural economies taking into account local resources and needs. Such "System Approach" will enable to innovate and deliver need-based technological solutions to

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well-identified local problems/challenges through adaptive research involving community as well as S&T knowledge hubs across rural areas. Such mechanism for scaling up with more S&T-NGOs (Core Support Groups) as drivers of change at the grassroots level will facilitate in bridging projected skills gaps and ensuring inclusive growth trajectory by creating vibrant social enterprise ecosystem in the country. It will also contribute to strike a balance of rural-urban divide for improving quality of life and creating job opportunities in rural India.

Keywords Inclusive growth · Rural livelihoods · Social enterprises · Technology adoption · Adaptive R&D · Renewable energy · Waste management · Technology transfer and skill development

1 Introduction

Since Independence, India has endeavored to bring economic and social change through Science and Technology (S&T). Innovation, which includes new technologies, delivery models, social and market changes, remains important for India's development agenda. It is now being realized to promote rural development that is based on scientifically valid understanding of problem contexts and technological solutions that are economically viable, socially progressive and ecologically sustainable. Due to known contributions to improved socio-economic conditions of the masses, innovation systems and technologies therein are seen as a driving force for faster and inclusive rural growth and development.

Despite several affirmative actions and investments on the part of government and other development agencies, the goal of faster and inclusive rural growth and development through innovation systems, technology generation, development and delivery remains to be achieved. There is still huge unmet potential for rural development using the innovation systems and technology led growth. With increasing globalization and inequality, and emerging concerns about climate change and other environmental disruptions, the development context and the demand for critical technologies within India is also changing both in rural as well as urban areas. A rural-urban development divide presents challenges to achieve the goal of growth with equity. Rural entrepreneurship and business incubation nowadays is being considered to play important role in economic development of developing and least developed countries and their rural communities, which tops the list of sustainable development goals (SDGs) to eradicate poverty and hunger in the development agenda (Habito 2010; UN-ESCAP 2017). Despite rapid economic growth, effort to translate this growth to livelihoods, incomes, productivity, manufacturing capacities, and well being for rural populations and sustainable use of resources is real cause of concern for green growth and development (OECD 2011; GOI 2015). Organization for Economic Cooperation and Development and the International Labour Organization in their strategies for local job creation, skill development and social protection have emphasized on maximizing skill development and training as one of the policy suggestions for their member countries, and also effective approaches to achieve viable livelihoods in different rural sectors (OECD & ILO 2011, 2012).

Present paper share practical experiences and analyzes some field level interventions though case studies of some S&T based Core Support Groups (CSGs)[1] from India to address key questions about innovation systems and technologies for rural growth and development that emerge in this context. Technology products and packages developed/customized and innovations made by these field based groups in critical areas like energy and resource management through strong interface with national R&D hubs are demand driven, relevant and have been well received by the people in rural areas. Paper also discusses emerging challenges for inclusive growth and driving factors responsible for expanding such network for vibrant and visible transformation in rural areas through technological intervention and social inclusion.

2 Innovative Technology Solutions and Delivery: Case Studies on Rural Growth and Enterprise Creation

2.1 Food Processing Technology

Case Study I: **Innovative Solar Cabinet Dryers**

Technology Product/Package Details Food processing industry is struggling hard to come out from the present poor state of affairs considering that 30% of the fruits and vegetables in India are wasted due to lack of adequate food processing units. To address the issue of value addition at source to food products, an innovative technology in the form of solar cabinet dryer has been developed by Society for Energy, Environment and Development (SEED), Hyderabad, a CSG to process fruits, vegetables, and forest produce with zero energy cost. The integration of solar–thermal energy and solar photovoltaic technologies in the design and development of solar cabinet dryer has resulted in a new and innovative technology called '**solar-powered**

[1] **Core Support Groups (CSGs)**: CSGs are S&T based NGOs/field institutions supported by SEED, DST, GOI to promote and nurture them as "S&T Incubators/Active Field Laboratories" in rural and other disadvantaged areas of the country to work and provide technological solutions and effective delivery of technologies for livelihood generation and societal benefits. These CSGs identify real problems on the ground and converting them to research challenges in terms of S&T and evolving workable technological packages for adoption by community/end users for better quality of life and livelihood gains. In this process, Core Groups ensure hand-holding at the community/users level with backward and forward linkages. The technologies developed/customized and innovations made by these field groups through strong interface with national R&D hubs are demand driven, relevant and have been well received by the people in rural as well as urban areas as well. Such long term core support in phased manner is operational under Technological Advancement for Rural Areas (TARA) scheme of DST being handled by author. Currently, 25 national level organizations with core team are engaged for delivering need based and affordable S&T solutions on challenging problems at the grass roots levels in farm as well as non-farm sector from diverse regions across the country (Details about TARA and CSGs is available at: https://www.dsttara.in).

solar air dryer' successfully tested in the field. The hot air, with moisture content in the cabinet, is exhausted continuously by solar fan operated by the solar photoelectric power. This phenomenon introduces forced circulation in the cabinet, resulting in high efficiency of the dryer. The source of thermal energy required for drying and for supply of photovoltaic power are from solar radiation during the day. In this innovative technology product, a close synchronization is maintained in regulating and controlling the drying process between evaporation of moisture from the product and speed of the exhaust fan. This regulates solar power to the fan through drying process with variable solar intensity during the day. The new solar-powered solar cabinet dryer is found to be effective product in food processing technology, especially in dehydration processes. Variety of dryers of different scale have been developed by SEED which have shown immense potential especially in dehydration process of fruits and vegetables for value addition of products at the farmers' level and preservation with long shelf life. Thus, eco-friendly technology product and package developed by SEED for quality drying having a payback period of 4–5 years can led to establishment of micro-enterprises, and creation of employment opportunities for youth and women groups (Box 1). Considering that only less than 5% of the total production in the country at present is being processed, introduction of such

Initial Start Up trials & Outreach:

- **Solar cabinet dryers (SDM-50 Model): Innovative and novel technology**
- **Being used on a commercial scale by some micro-enterprises in AP**
- **Special model of drier also developed for Himalayan fruits processing and being adopted in Uttarakhnad.**
- **Technology flow – high**

Technology details	Technology Package
Product produced	Fruit Bars/Jelly
Raw material used	Fruit Pulp, Preservatives
Salient features	High retention of micro nutrients, moderate & even drying, Clean and hygienic end product without contamination
	Value addition, High shelf life, Solar dehydration processing with zero energy cost
Advantages: Social/ecological /economic	Reduction of post harvesting losses of fruits & vegetables. Useful for SHG's and rural micro-enterprise
	Sustainable Income, Eco-friendly & Zero carbon emission
Energy used	Solar Energy – Zero energy cost
Jobs potential	5 – 10 entrepreneurs
Investment	Ranging between Rs. 8 – 11 lakhs
Payback period	Around 4 – 5 years

Box 1 Solar cabinet dryer—fruit and vegetable processing technology developed by SEED, Hyderabad

need based and field tested innovative technology will help immensely in reducing the post-harvest losses by processing of fruits and vegetables and forest produce. Besides, it will facilitate value addition and income generation for farm producers to enhance livelihoods as an individual or group enterprise at village level as well with cluster approach of appropriates scale. During off-season, the entrepreneur can also make use of such systems to produce powdered spices, which are having good market demand nowadays.

Technology Adoption and Outreach

Micro-enterprises Creation and Skill Development In terms of technology flow and adoption impact, so far 200 cabinet dryers have been installed in 15 states in the country, and enabled creation of 100 micro-enterprises in solar food processing technology of various products covering 18 States. It is noted that the innovative technology of dehydration developed by SEED is already applied to nearly 86 food products and starting micro-enterprises across the country with wide range of products like fortified fruit bars of different combinations. As a start-up, micro enterprise with 5 solar dryers or equaling with a capacity of minimum of 1000 kg (1 ton) of fruit bars or other food products for single dryer per annum for any Self Help Group is found to be most suitable and economically viable venture project for cluster of villages to be financed by Banks in MSME sector. It will lead to

- Comfortable surplus to repay Bank Term Loan in 5 years which includes moratorium of 6 months.
- Provides monthly salary for three members of the group in processing work of the unit and another two members as administrative staff in addition to surplus available.

Capacity Building and Replication Thus, integrated technology packages developed and customized by SEED as per agro-climatic regions for variety of produce has created opportunities to build capacitates and generate job in rural settings and enabling entrepreneurs, self-help groups, and stakeholders to utilize them with zero energy cost and clean energy in producing nutritive products with quality control. Replication of this technology is already proven in the field as found in the case of Himalaya fruits in Uttarakhand state with adoption and creation of micro-enterprises in making fruit bars at the local level through SHGs or women's group. Case analysis revealed that these dryers which can be designed to the desired sizes are multi-purpose and applicable to multi-crops and works for 300 days in a year (Rao 2016).

Eco-friendly As a green energy system with reduced carbon footprints, solar energy use through above-mentioned solar dryers eliminates usage of fossil fuel, reduces greenhouse gas emission and estimated to reduce 36,288 kg of carbon emission gasses per tonne of fruits bars.

2.2 *Waste to Wealth Technology*

Case Study II: Paper Recycling and W2W Technology

Technology Product/Package Details India faces severe environmental degradation where in solid waste is a major cause of concern. Paper use and disposal is growing at a rapid rate causing large amounts of wastage of paper. Since majority of the paper in India is still made from wood, thus, consumption of wood and therefore cutting of trees is also rampant. To solve the issues of waste utilization, deforestation and creation of jobs and new enterprises, Development Alternatives (DA), a CSG based in Delhi has developed TARA paper recycling technology package. This technology package has shown immense potential to facilitate and support small groups and organizations in rural as well as urban area for setting up small enterprises as profitable and sustainable businesses from recycling of waste paper.

DA provides a comprehensive "package of services" to ensure success for the recycling enterprises. The package consists of a set of custom designed equipment of different scale developed to perform various functions such as Hydra-Pulper to make pulp from waste paper, Hollander Beater to make pulp from waste cotton rags, Univat for the formation of sheets, whereas the TARA Screw Press is used to remove the excess water from the formed sheet. Polishing of the dried formed sheet is done through Calendering Machine, and Semi-Automatic Cutting Machine is used to cut the sheets into desired size. A photo-sensing safety device is incorporated in both the equipment for operational safety. The installed load for the production system varies as per capacity. It is estimated that a commercial paper recycling package can recycle one tonne of waste paper per month with payback period of 3–4 years as yielding up to 15,000 kg of finished paper of assorted quality and a value addition of more than Rs. 15 lakhs per annum (Box 2 and Fig. 1).

Technology Adoption and Outreach The TARA Paper Recycling Technology package is of different scales aimed at commercial entrepreneurs, community groups, corporates, government departments, schools and any other Institutions to make use of recycled paper in any form. The Technology is not only environment friendly, but also help to reduce dependency on forest resources and carbon footprints as well. More than 200 schools, Government, and Institutions have adopted the paper-recycling package for conversion of waste paper along with hosiery waste into value added products as an incubated, start-up business. To add value further, and for creating access to extended markets for fibre based enterprises, DA has been able to introduce waste to weave (W2W) technologies to use locally available jute fiber waste and PET bottle waste yarn for making various products like bags and fashion accessories. W2W has been introduced in reviving 3 artisanal clusters of Kalapuram, in Datia, Jhansi wherein traditionally skill set and capabilities required to develop handloom products exist. Taking forward the larger goal of providing market access to rural poor through technology based livelihoods, range of hand-woven fabrics and green lifestyle products are under development by the use of recycled PET (r-PET) bottle yarns integrated with the natural fiber (cotton/silk/wool) yarns with the

Technology details	Technology Package: Paper Recycling	Technology Package : Waste-to-Weave
Product produced	• High quality handmade paper sheets of various GSM (80-1500) • Value added products(Files, file folder, envelopes, letterhead, pad)	High quality textile
Raw material used	Waste paper, paper boxes, denim cutting, hosiery materials, jute fibres etc.	Various combinations of recycled yarn from waste PET bottles and cotton/silk yarns
Salient feature	Uses 100% mix of paper wastes, cotton wastes and natural fibres	Uses around 50-60% recycled waste
Advantages	Technology package includes testing of raw materials, design of process & equipment	
Social/economic/ ecological gain	Children/women producing quality materials, savings of trees for paper making, replacing plastic bags with paper bags, very useful as rural enterprise for rural youth	
Energy used	Between 02–16 HP depending on capacity	Nominal power for TARA loom operation
Jobs potential	Around 10–12 women (2 for schools)	Around 5–6 women
Investment & capacity	Rs. 2–2.5 lakhs (for schools: 6-8kg/day), Rs.7–7.5 lakhs (Communities/ SHGs: 25–30 kg/day), Rs. 16–18 lakhs(Commercial unit: 70–90 kg/day)	Starting from Rs. 5 lakhs based on productivity
Payback period	Around 3–4 years(for School – awareness purpose, not for profit)	Around 2–3 years


Box 2 Waste to Wealth technologies developed by Development Alternatives, Delhi

cutting edge technology of TARA Loom developed by DA. A group comprising of seven semi-skilled and unskilled women weavers from Kalapuram have undergone the skill development program by engaging them in developing high quality hand woven products ensuring market linkages.

A large scope in the niche market is being explored by this CSG (DA) for the hand woven product range developed via TARA Loom technology and handmade stationery products utilizing the paper technology.

Fig. 1 Waste-to-Weave: Technology based innovative model to accelerate rural livelihoods

2.3 Clean Energy Access for Domestic Use and Micro-enterprise Creation

Case Study III: Pedal Powered and Solar Powered LED Lamps

Technology Product Details Vigyan Ashram (VA), another CSG based in Pune, has been working on developing low cost, easy to assemble and durable LED lamps.

Various types and capacity of LED lamps capable of charging by Solar PV panels and Pedal Power generators are developed by VA and technology know how has been transferred to BOPEEI Pvt Ltd., a Pune based social venture (www.bopeei.in) for scaling up and large scale dissemination. However, VA has been engaged simultaneously in its efforts to deliver technology at grassroots level by building capacities and conducting skill training for tribal youth in Solar LED lamp assembly and repair; and for installation and assembly of Solar street lights.

Technology Adoption and Outreach Solar and Pedal power LED lamp technology has been disseminated in tribal areas of Chhattisgarh and Madhya Pradesh State by adopting concept of "learning while doing". In this endeavor, 372 rural youth were trained in a year in assembly and marketing of Solar LED lamps as '**Village level Entrepreneurs**' (VLEs). Besides, 18400 units of LED lamps have been provided by VLEs to tribal households that evidently indicates their effective role to source and use technology led employment opportunity as well as providing lighting service in remote rural areas. In such an effort, 11 tribal villages have been converted into Solar Gram with 100% households adopting solar LED lamps. For such initiatives towards social inclusion, Vigyan Ashram got recognition as Development Marketplace Award for scaling up the efforts in Chhattisgarh and Madhya Pradesh.

Case Study IV: Domestic level Solar Egg Incubator

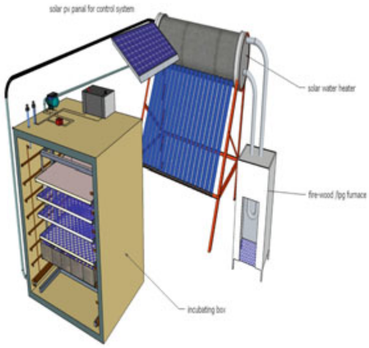
Technology Product Details Poultry farming is well-adopted and profitable business in rural India. Apart from bigger scale contractual poultry farming, backyard poultry farming is still regularly practiced in rural areas. One main issues faced by the small farmer is the sourcing of chicks in small amounts (few hundred and thousands) for running poultry independently. Though, commercial hatcheries available in the markets are of huge capacities and requires generator backup for continue power (heating) supply. Recognizing this need of the marginal farmer "**Domestic Egg incubator cum hatcher**" has been developed by VA having potential livelihood option in rural areas with a capacity of 100–1000 Egg per batch (Box 3). This cost-effective technology product maintains temperature in the incubator using solar water heater heat transfer technique or by using LPG/electricity in non-sunny days. The technology is commercialized after successful field trials in 2014–15, and the organization is conducting regular trainings for farmers/SHG members for disseminating this technology. Business model has also been developed for this technology with 9 months return on investment (ROI) of Rs. 80,000.

Technology Adoption and Outreach Analysis of this product under field has evidently indicated that it has been designed by considering needs of rural community with innovative features like less energy consumption—Can be used with lead acid based invertor system to handle grid power failure up to 10 h. So far this technology is adopted by 10+ farmers/SHG's serving 500+ individual small farmers (customers) and at institutional level by Krishi Vigyan Kendra–Baramati, Mahatma Phule Krishi

Technology details	Technology Package
Product produced	Domestic Egg Incubator
Raw material used	Insulated Cabin box , Temperature/Humidity control system , PLC system with DC motors etc.
Salient features & innovativeness	Lower energy consumption with option of electricity grid/Solar water heater based heat transfer. Advanced automation features for temperature, humidity & tray rotation system.
Advantages	Easy-to-Operate, completely automated unit with higher hatching rate.
Social/economical/ecological	Very useful as rural enterprise : Cost-effective and affordable system.
Energy used	Between 400 and 550 Watt depending on capacity
Jobs potential	Enterprise can serve demand for 2 – 3 villages (100 to 150 individual farmers)
Investment	Ranging between Rs.0.25 to 1.25 Lac
Payback period	Around 9 to 13 Months

Specific Features:

- **Domestic level poultry egg incubator.**
- **Available in regular (grid power) & solar powered model.**
- Solar water heater based heat exchange mechanism: **Special model also developed for off grid or very high & frequent power cut-off villages based on solar water heater.**
- **Higher hatching rate (80 to 85%) with fully automatic control system for handling by semi-skilled labour at village level.**
- **Very useful for SHG's, poultry farmers, rural youth and for tribal belt.**

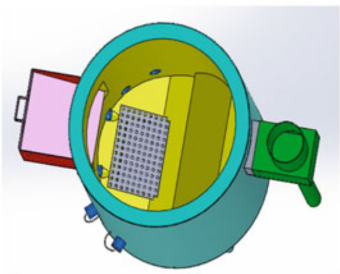


Box 3 Solar egg incubator (100 egg capacity) for small poultry farmers/Woman self help groups developed by Vigyan Ashram, Pune

Vidhyapeet–Rahuri in Maharashtra. This field tested technology product is now being commercially manufactured by M/s—Future Innovative Systems in various sizes like 100–1000 egg capacity and power operation mode as Grid powered, Solar and Fire wood based water heater as per need and demand by users.

Case Study V: Improved Cook Stoves

Technology Product Details Technology Informatics Design Endeavour (TIDE), Bengaluru, a CSG working on innovative technological solutions in renewable energy sector has developed a series of energy efficient stoves to meet the demand for informal as well as rural sector. R&D, field testing, manufacturer identification, negotiation of commercial terms and deployment of 4 models of such stoves in 2–4 sizes has reached to three thousand users and technology has been transferred to 4 manufacturing units after a non-disclosure agreement. This translates into saving of 37,008 tons of firewood (Equivalent area of forests saved: 3701 ha), mitigation of 55,512 tons of CO_2. These interventions have also provided employment for 8760 people. For instance, as compared to conventional stoves, PYRO a multi-purpose stove has been designed and developed by TIDE in 5 capacities to meet every cooking requirement for optimum heat utilization and as per users' convenience (Box 4). The key scientific principles responsible for increasing the efficiency of PYRO stoves are increase in combustion efficiency, high generation temperatures and increase in heat



Cooking Devices developed by TIDE, Bengaluru

Micro Solar Dome and its Usage : Designed by NBIRT, Tripura

Box 4 Energy efficient devices developed by Core Groups with reduced carbon footprints: Clean energy access for social enterprise and livelihoods gain utilization efficiency. Increase in combustion efficiency is obtained by ensuring very good mixing between the air and the fuel.

Product from TIDE, Bengaluru	Unique features as compared to conventional stove	Fuel saving	Techno-economics
PYRO Tava (A long stove with a flat plate used for making rotis, dosas, etc.) for use by commercial (street food vendors, canteens, roadside eateries, dhabas) and institutional kitchens. 	• Controlling heat input possible • Complete combustion, high and uniform temperature • Optimally designed stove interiors, chimney and cold face insulation; smokeless • Convenient accessories • Fuel saving, user convenience, managing air fuel ratio, increase of surface area of vessel, quality assurance, longer stove lives with less maintenance	With LPG replacement – Rs. 11,000/month With fuel saving – Rs. 5,400/month	Payback period 3 months 6 months

Technology Adoption and Outreach Currently, it is estimated that commercial cook stoves developed by TIDE are being used in 400 towns of Tamil Nadu spread over the entire state, in 5 towns of Karnataka and 3 towns in Kerala. TIDE has also developed training manual for the stove construction, quality assurance forms, detailed engineering drawings, presentations showing commonly made mistakes, leak testing, and videos of fabrication process. Recent study indicates that 46 women trained by TIDE to create viable livelihood options to run energy efficient enterprise are self-reliant, contribute in their children education, role models and are good communicators. To scale up these initiatives, TIDE has established sister concern i.e. Sustaintech India Pvt. Ltd. which operates in South India to develop business models in fuel-efficient stoves dissemination. Sustaintech emerges out of TIDE, has been conceived as a socially sensitive, profit making, scalable enterprise aiming to positively impact lives and also to (a) reduce firewood consumption (b) arrest deforestation and (c) contribute to climate change mitigation efforts. It uses market mechanisms to offer fuel efficient wood burning stoves to small businesses like street foods, schools, roadside restaurants, tea/coffee vendors and other commercial kitchens. This business model has secured investments and has been identified as one of the top 3 business models in the Asia Pacific region. This approach to create

Sustaintech has helped TIDE to address legal limitations and barriers to achieving scale and delivering triple bottom line impact of grassroots enterprise model of user friendly and energy efficient wood burning stoves (brand name PYRO).

Two decades of experience in designing for other similar clusters has contributed to the easy acceptance of the stoves at the users' level. Such innovative work by TIDE in the past has won international recognition i.e. Ashden award for Sustainable Energy and Social Venture Network Innovation Award 2014.

Case Study VI: Micro Solar Dome (MSD) Technology

Similarly, NB Institute of Rural Technology based in Tripura has developed cost effective and eco-friendly solar lighting device, which would prove to be a boon for the urban slums and rural households in the country that do not have reliable access to electricity. Micro Solar Dome (MSD) captures sunlight through a transparent semi-spherical upper dome and concentrates it inside a dark room (Box 4). The light passes through a sun-tube having a thin layer of highly reflective coating on the inner wall of the passage. It also contains a lower dome having a shutter at the bottom that can be closed if light is not required in the daytime. It is leak proof and works for almost 16 h daily i.e. throughout the day and 4 h after sunset using higher capacity solar PV modules to improve indoor livelihood activities and lighting needs with saving of fossil fuels to a great extent. According to a testing report, the illumination level of the light during mid-day goes as high as a 15 W LED bulb with zero carbon emission. Field trials have been conducted and Micro Solar Domes are being installed by slums dwellers and rural households in remote areas for eradicating the problem of lighting at affordable price with reduce indoor pollution and expenditure on kerosene, which helps them to live a better standard of life as well as livelihood generation (weaving, wool combing etc.) with less expenditure on electricity. Further, efforts are being made to design and install MSD through adaptive research for need-based modifications as per climatic conditions and varied type of housing like snow covered region, and for stone ceiling in mountain areas.

3 Discussion: Success Factors and Drivers of Change for Technology Customization, Delivery and Scaling Up

3.1 Technology Growth Model of Core Support with Local Institutional Arrangements

Comprehensive analysis of interventions made by abovementioned S&T based field groups (CSGs) to provide technological solutions clearly indicate effective role being played by their respective core teams comprising scientist, technologists and social scientist in customization/development and delivery of technology products and packages though *cycle of innovation and field trials, incubation, field demonstration* under field conditions and make them ready for replication and high impact

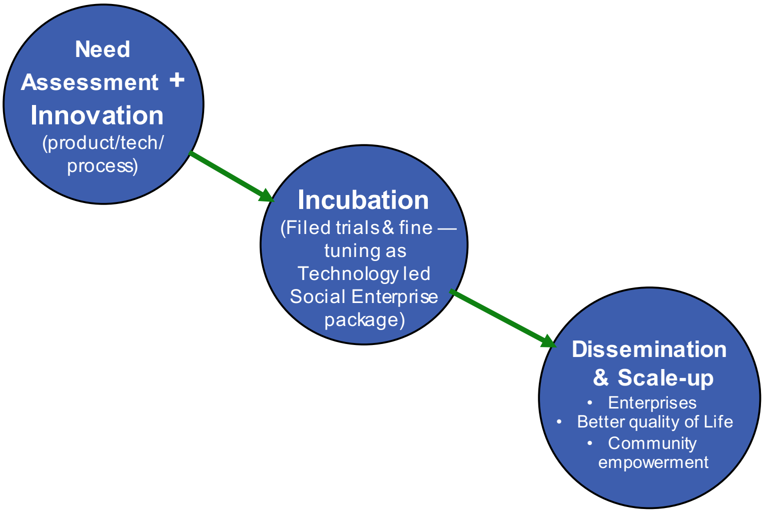


Fig. 2 Strength in Core Support model for nurturing S&T-NGOs (CSGs): looking for scalable green technological solution and effective delivery through participatory action research with local institutional arrangement

scale up (Fig. 2). Technology products and packages discussed here have shown strong replication potential to solve various energy, waste management and livelihoods related problems of the rural society. In all the cases described above, the very concept of micro-enterprise as individual or in a group in the rural and urban set-up gives an excellent capacity for the production, management, and marketing, thus enhancing the capabilities of women and youth for promoting and scaling up starts up as evidently found particularly in case studies on paper recycling (DA), solar dryer (SEED) and energy efficient cooking devices (TIDE). It was also found that such scalable interventions are highly efficient, improve working conditions and bring environmental and social benefits.

From operational point of view to make visible impact and adoption at the user's level, it was found that CSGs as such innovates for better interface of science and society and they carry out activities that enable the creation of social, economic and environmental impact in rural and semi-urban areas as seen in the case of TIDE, DA, SEED and NBIRT. In this process, institutional partnership with National level S&T knowledge hubs like Centre for Sustainable technologies (IISc), Bengaluru with TIDE was found critical to ensure development and delivery of quality products. Further, projection related to reduction in carbon emissions and saving of carbon/household is reported very encouraging in field level application of energy efficient devices as seen in case studies I and VI for domestic as well as commercial use. For instance, carbon emission reduction in case study VI is reported about 27 kg per month by use of single Micro Solar Dome with low maintenance. Therefore, the concept of such technological interventions to overcome energy vulnerability and effective resource usage having essential component of capacity building with local institutional arrangement as evidently seen in all the cases has shown potential for large scale dissemination with policy level decision for customization to promote individual and group enterprises. This will ultimately contribute to the recent initiatives of carbon neutrality and in conservation of natural resources with reduced extraction of fuel wood from forests and natural habitats, which is a priority at the local as well as at the national and international level. Besides, quality leadership and in-house technical capabilities and strength to work with the community through strong social engineering component by core team (s) deployed under Core Support Model of DST have been found major factors in effective delivery and adoption of such need based technological solutions.

3.2 Strategizing Innovative Systems and Technology Deployment

Other factors, which were found responsible in strategizing innovative systems and to evolve workable technology products/packages for rural transformation by these CSGs, are:

- **Innovations that accelerate new economic opportunities** and enhance incomes i.e. technology solutions that.
  - Provide local entrepreneurship and employment (LED Lanterns, paper recycling—by VA, SEED & DA)
  - Add value to local resources (Solar dried products—by SEED)
  - Enhancing productivity while yielding high economic returns
  - Providing new generation of services (Clean energy services and paper recycling—for domestic use and enterprise creation—by TIDE, VA, DA, NBIRT)
- **Need based intervention in challenging areas**: 3A (Appropriate, Affordable and Accessible) technological solutions and systems management.
- **Pro-active approach** addressing location specific issues.
- **Strong networking at field level**: S&T based Core Support Groups-Institution partnership + interface with R&D institutions to address critical issues for vulnerable sections and informal sector.
- **Strong social engineering component** to produce large level and wide effects in rural settings—Hand holding and skill development—Community owned and Community Operated model.
- Involve Panchayati Raj Institution (PRI) and local governments in scaling up with **local institutional arrangements**.
- Catalyze and promote collaborative linkages—Scaling up at local, regional and national level.
- **Evolving replicable models of <u>different scale</u>** for rural resource management (natural as well as human capital), and economic growth to enhance the local livelihoods and address vulnerability and developmental issues.

Thus, for traditional activities in the rural areas, there is a need to strengthen the knowledge, skills, and infrastructure already available and scale them up in a business model, in order to bring significant impacts in terms of better output and efficiency. A range of skilled and unskilled employment opportunities for pre- and post-installation services related to electricity supply and mechanical and civil work can be generated as evidently found in the case of energy efficient devices developed by SEED, DA & VA. If properly pursued, such emerging technology packages/products for effective resource management and energy efficient systems as described above through case studies would provide immense employment opportunities to people in rural settings, who are currently migrating to bigger cities or industrial areas in search of jobs. Large-scale replication and application of such emerging technology packages by CSGs at the grassroots level can play a lead role to diversify rural economies, to improve the productivity of rural areas and to reduce the existing environmental damages of the eco-systems with clean energy access (UNDP 2012). In this endeavor, the Gandhian concept of resource use for the local market with upgraded technology needs to be properly synchronized by building local capacities with new wisdom of S&T for resource use in decentralized way to transform rural livelihoods and ensure village sustainability (Joshi 2008).

3.3 Innovations for Social Enterprises

*Technology products and packages discussed here have shown strong replication potential to solve various energy, waste management and livelihoods related problems of the rural society. Case studies clearly indicates that as social entrepreneurs, S&T based CSGs can act as the "**Change makers**"for addressing society's most pressing problems through appropriate technological interventions, seizing opportunities to improve technology delivery systems, invent new approaches for technology adoption at the users' level, and provide innovative and affordable technological solutions with strong social engineering component for societal benefits.* Improved Innovative solar cabinet dryer technology by SEED, Hyderabad, Energy Efficient Cooking Device by TIDE, Bengaluru with benefit of reduced carbon footprints and waste paper recycling for effective resource management by DA are some of the innovative technology products and services for improving quality of life and livelihoods of rural and marginal communities.

Thus, technology as such creates innovative options to scale up for social enterprises ensuring social, environmental as well as economic sustainability (Swaminathan 2008). In this process, these groups have been able to build capacities and engage rural youth to innovate and provide such need-based services by opening opportunities in the social enterprise domain as found in all the cases to find innovative solutions to social problems with creativity for change. Thus, need is to trigger a sustainable social enterprise ecosystem to make a more meaningful contribution to rural society through technology driven developmental initiatives (GOI 2015), which has been found very effective in technology led growth model of Core Support of DST with local institutional arrangements by engaging S&T-NGOs as CSGs.

3.4 Promoting and Scaling of Start-Ups: Challenges

These case studies derived from field observations and tested by local communities also identify that focus only on technological solution is not enough; approach should also include enhanced capacity locally to adopt new adaptation strategies in holistic way with more livelihoods options. Critical analysis on successful technology delivery and adoption aspects justifies the role of civil society organizations with S&T capacitates (as technology action groups) on 'problem based intervention' for pro-poor innovation rather than 'solution based thinking' with systems approach covering managerial and social engineering aspects as well. Most remarkable feature of almost all these technology products and packages evolved is that they have been designed and can be scaled further in the form of standardized mode for replication as per location specific needs through intensive collaboration process amongst technology generator, providers and users as seen in the case of solar cabinet dryers developed and customized by SEED for different agro-climatic regions. Analysis of these case studies also recognize and identify the practices of science based civil society organizations as important actors of change in innovation system (to enable technological as well as non-technological or process innovations together) and in delivery process chain i.e. through technology user's groups or women's Self-help Group working within the settlement who understand the system and accept the responsibility as catalysts of innovation. *This process mechanism is absolutely essential to bring better local participation and diverse actors together who have capacities for innovation and to perform various roles/support knowledge inputs in sustaining technology driven developmental initiatives* (Pataki and Vase 2003; Kochendorfer et al. 2000). However, there are some major challenges for success and effectiveness towards economic, social and environmental returns (Nair and Iyenger 2008; Josefina and Abilay 2014):

- **Innovative Business Models for local Value Addition**: It is imperative that transformation towards a truly sustainable society be driven through business models with distributed epicentres of local value creation that rely on the regeneration of natural resources, access to clean energy, right-sized technology and skilled human resources. This will need innovation at systems levels higher than that of simple products and services by enabling social equity with local institutional arrangements for last mile delivery of basic products and services for poor.
- **Ecosystem Challenges**: It was seen in the case of TIDE that the street food sector was exposed first time to a new low carbon technology. Therefore, it is important that the time taken for confidence building leading to adoption of new/improved technology i.e. stove purchase pick up slowly with perception of change.

- **Consumer Finance**: Loan schemes of Banks and MFIs needs to be compatible with the needs of the sector—Developing financial mechanisms in support of inclusive innovation initiatives and related intermediary institutions.
- **Challenges for Social Inclusion**: Engagement of CSGs for social inclusion in a country that is extremely diverse and to be constantly engaged with the people at the grassroots level for better quality of life and livelihood gain as evidently found in all the case studies is itself indicative of CSG's commitment for inclusive growth to address the needs of diverse population. They have capability and creativity to provide scalable technological solutions as per location specific needs. However, it is equally important to strategize the management support system (technical, sales, servicing and HR) to address the needs of diverse ecosystems' and communities.
- **Inclusive Innovations**: Need is nowadays being felt for inclusive innovation for delivering better quality services/products for improving the welfare, creating livelihood opportunities, and empowerment of lower-income and excluded groups/marginalized population, and to support the scaling up of successful initiatives as evidently seen in above discussed case studies of business process innovations to benefit larger section of excluded population to serve local needs and also to adapt them to specific rural context. Certainly, such technologies and innovative delivery processes have the potential to achieve scale and wide scale utility like ICT use in health care and other support services to facilitate inclusive innovations. This requires inclusive policies for inclusive growth as also advocated by Heek et al. 2013; Mashelkar 2014; OECD 2014, 2015 that will contribute to social inclusiveness.
- **Address the problems of Start-up**: Creation of Rural business incubation facilities to provide the client with an ecosystem to support institutions and the facility to serve its purpose to become a full-fledged entrepreneur.

4 Conclusions: Technology led Scalable Solutions and Services for Rural Growth

Though there are many entities interested in doing related action research work for the development and dissemination of technologies for rural transformation, the spread of rural technology has been diffuse, uneven, and slow and its full potential for generating a rapid multiplier effect in rural economy has remained unrealized. The main constraint preventing advances in technologies for rural application from reaching most villages in rural areas seems to be the lack of local technology action groups who can assist in the assessment of the technology needs and the current technology status/gaps of different rural occupation groups, i.e. farmers, rural artisans and the landless, to enable them to add value to their products and services with upgraded technology of appropriate scale.

Comprehensive analysis of above discussed case studies clearly show the ways that attention is required to embedding the results of such field level action research in policy; using research intermediaries with system approach and communication channels to ensure the results of action research and knowledge generated reach large section of affected communities in rural areas. Case studies also point out that capacity building to adapt towards technological interventions for micro-enterprise creation and livelihood gains really requires local institutional arrangements in facilitating to identify suitable technological options and scale up existing knowledge tools and approaches with appropriate one for adaptation to address emerging developmental challenges at the grassroots level. Critical analysis on successful technology delivery and adoption aspects justifies the role of civil society organizations as CSGs with S&T capacitates on 'problem based intervention' for pro-poor innovation rather than 'solution based thinking' with systems approach covering managerial and social engineering aspects as well. Most remarkable feature of almost all technology packages evolved is that they have been designed and can be scaled further in the form of standardized mode for replication as per location specific needs through intensive collaboration process amongst technology generator, providers and users. These studies also illustrate ways in which technological interventions with systems approach to evolve technology products or packages in participatory mode provide a practical means of improving people's immediate requirements, and provide them with increased capacities in terms of green and affordable technological solutions for better quality of life and services (Raghunandan 1988; Gladwin et al. 2002; Agarwal 2005, 2013; OECD 2011).

Therefore, Science based scalable technological solutions for sustainable livelihoods and creating vibrant ecosystem for social enterprises for people in rural and remote areas as evident from above field based case studies for macro level application can certainly address the key issue of conservation of natural resources, employment and vibrant ecosystem for social enterprises. Such technology benefits with novelty in ideas and delivery will open new alternative livelihoods opportunities to connect with recent national initiatives of Starts up India, Clean India, Ek Bharat and Shreshta Bharat, Make in India, Skilled India involving local community through good management practices by engaging and creating more S&T based action groups (CSGs) committed to work in challenging areas of rural problems. Further, technological intervention in each case has also indicates its contribution towards attainment of Sustainable Development Goals (SDGs) particularly for improved income and livelihoods; gender equality and women's empowerment, renewable energy, protect and restore the planet's environment and natural resources and developing partnership and linkages for inclusive and sustainable economic growth (UN-ESCAP 2017). These CSGs as technology action groups can play an important role to rise to the challenge of such initiatives to speed up rural growth in inclusive manner and enhancing technology flow and interaction between people from local to state, regional and national level.

5 Way Forward: Policy Interventions for Effective Technology Facilitation at Bottom of the Pyramid

From abovementioned case studies and discussion, it is understood that strategies for the most effective "Innovation Systems" (which include the generation, delivery and access, and use of knowledge and technology for development) is the key to the future of rural development in India. Analysis of work carried out under field conditions also makes it clear that technology development and delivery need both technological innovations (adaptive research for solar dryer, paper recycling etc.) and social inclusion through technology user groups/social enterprise such as TARA of DA and Sustaintech of TIDE, a farmer producer company or a women's SHG or a co-operative marketing federation or a macro-economic policy like tax incentives for some rural manufacturing as well.

Systems approach to promote the research, development, transfer and diffusion of environmentally sound and affordable technologies need to be established and strengthened. The use of enabling technology, in particular information and communications technology can be a very effective tool to involve rural community in such process of change. Further, if India has to make leaps in resource efficiencies, mechanism for zero waste to promote circular economy needs to be put in place to ensure that benefits of technological innovations reach the base of the pyramid with local institutional support systems and arrangements to accelerate their adoption and absorption among end users. In this context, Core Support model of TARA scheme of SEED, DST has shown its strength and potential for effective technology facilitation mechanism at the grassroots level that includes need based technology and innovation capacity building at local, regional and national level to promote knowledge sharing for skill development and economic growth as well. As such for societal engagement, the bridging role of NGOs are of importance to provide the needed solutions for the common problems by translating the output from science, technology and innovation related activities for inclusive development (Chandran et al. 2015). Such institutional network at grassroots' level involving community at large in rural landscape can effectively contribute to foster innovation ecosystem in India for sustainable economic development. In this context, development of innovative day light capture device i.e. Normal Micro Solar Dome (MSD) by NBIRT, Tripura costing about Rs. 500/-, and PV integrated MSD with USB port for mobile charging costing Rs. 1700/- has justified its immense utility in remote non-grid areas for lighting in slum and village habitat. Such need-based intervention with socio-economic impact benefits provides women and children in particular to have more time for education, leisure and economic activity. While, to address such issues of social inclusion and skill development, Integrated Rural Technology Centre (IRTC), Palakkad, Kerala has been able to develop microwavable earthenware pots through adaptive research and its large-scale production by building capacities of local potters. Similarly, cost effective water heating panel developed by another CSG i.e. Himalayan Research Group (HRG), Shimla to meet the domestic need of water heating in remote mountain areas has helped not only to build capacities of artisans to fabricate them locally but also to reduce dependence of mountain community on fuel wood collection from forest and associated women drudgery (Box 5). Thus, novel ideas of innovative product design and its demand at the user's level has helped to strengthen the livelihoods of traditional artisans in village set up itself. Such interventions of use in daily lives from indigenous technologies, products and services show important role being played by S&T based civil society network to provide innovative and affordable technological solutions with hand holding for social enterprises. Such field based interventions clearly demonstrate that **Core Support Model for S&T-NGOs** provides excellent opportunities for inclusive innovations with scalable technological solutions, which can effectively address the challenges at the grassroots level effectively to improve the welfare of excluded groups (OECD 2015).

Specific Features & Economics:

- **Simple and cost effective solar water heating system for resource dependent rural households in remote mountain areas.**
- **Can be fabricated locally – Alternative livelihood opportunity to build capacities of local artisans (carpenter).**
- **Panel coil hold 18.0 Liters of water and is heated to 70 – 80 ^{O}C within 30 – 45 minute of solar illumination.**
- **Rural household can draw 100-120 liters of hot water in clear sunny day for household purpose**
- **Reduced carbon footprints and save 25 – 30% fuel wood consumption.**
- **Help to reduce dependence on fuel wood from forest and associated women's drudgery.**
- **Economic viability and break-even will be achieved with fabrication of around 200 units.**
- **Able to achieve maximum 90 ^{o}C water temperature in full sun and solar space heating panel achieved heated air temperature of 65 ^{o}C (when outside temperature around 7 ^{o}C in winter month).**
- **65 units installed in Mandi and Kullu districts of Himachal Pradesh.**

Box 5 Cost effective Solar water heating panel for domestic needs of water heating in mountain areas: Developed by HRG, Shimla

Thus, policy interventions are needed to have more such S&T based action field groups, which can work in their respective area of strength to innovate and deliver need-based technological solutions to well-identified local problems through adaptive research involving community as well as National S&T knowledge hubs. They can be engaged in research driven community engagement through inclusive development projects in establishment of small pilot processing units, skill development, technology delivery, compliance with quality standard and product development. Need is to support and nurture such dedicated S&T based action field groups (CSGs) to address emerging challenges of rural-urban divide and to ensure that growth and development is to be implemented in an equitable, sustainable and holistic manner in the country. Having better synergy with communities, these groups with green innovation strategies have potential to significantly contribute to address issues and concerns in sectors that are key drivers of growth and employment such as clean energy, waste management, and green agriculture etc. In this process, interface will be required to develop strategies and support mechanism to influence and strengthen innovation in green technologies for rural transformation with skill development at R&D knowledge hubs. They can be engaged in green skill building and trainings in order to move forward the agenda for green growth and green skills to preserve or restore the quality of environment and social protection as well as practiced nowadays to shift from fossil fuels to renewable sources or recycling of paper to eliminate plastic bag production (UNEP 2008; OECD 2011; GOI 2012; Agarwal 2013).

According to an estimate, rural-urban rations will shift from 70:30 to 50:50 by 2055, which indicates that enabling ecosystem has to be created to strike a balance of rural-urban divide with investment in rural areas for providing quality services and creating job opportunities (Balakrishnan 2008; Deloltte 2014). There is an excellent opportunity that exists in the form of corporate social responsibility (CSR) to renew and re-energize investment in knowledge systems and institutions of learning, which can support social enterprises by developing appropriate system for fostering innovation and technology delivery for knowledge empowerment and development of the rural communities. The CSR spending by industry have the potential to make huge impact to create necessary momentum and contribute towards rural transformation by taking such initiatives of Core Support Model to the next level.

Rural non-farm productive activities can also contribute significantly to livelihoods gain and the well-being of rural communities to tap the potential of traditional foods and crafts with value addition in processing. This needs to be promoted with technology led growth strategies based on diversification in rural economies taking into account local resources and needs (UNIDO 2013). In this regard, CSGs can also facilitate efforts being made through national skills development initiatives to build skills of marginalized communities as well as helping SME sectors in bridging projected skills gaps with adaptation to green innovation and ensuring in inclusive growth trajectory by creating vibrant Entrepreneurial Ecosystem in the country (GOI 2012; Das 2015).

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Role of Major Forest Biomes in Climate Change Mitigation: An Eco-Biological Perspective

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Abstract The rapid alteration in the global climate due to anthropogenic activities has profound eco-biological impacts, which invariably affect the ability of natural communities to effectively perform ecosystem services. The eco-biological impacts could be viewed across various dimensions including loss of biodiversity as well as ecosystem goods and services, changes in phenology, prevalence of droughts and forest fires, disease outbreaks, reduced crop yields and increase in intensity and frequency of extreme weather events. Although, the natural ecosystems are innately endowed with the ability to maintain homeostasis by means of resistance and resilience, this ability to cope up is severely impacted by various other factors like deforestation, habitat fragmentation, land-use change and biological invasion, which exacerbate the effects of climate change. The eco-biological impacts of climate change are tied with socio-economic aspects by means of market values of the produce, poverty, undernourishment, livelihood security, etc. At this crucial juncture, forest biomes offer an immense ecosystem service towards climate change mitigation through carbon sequestration. Nevertheless, the three major forest biomes, viz. tropical, temperate and boreal, with their unique characteristics, vary in their response to climate change as well as mitigation potential and response. This review chapter aims to understand the varied climate change impacts and the crucial roles of major forest biomes in climate change mitigation and their various ecological services to formulate better forest management strategies.

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1 Introduction

Our Earth, the only known habitable planet has a long history of constant fluctuations in climate, alternating between warm and cold periods, which is evidenced by data from samples of ice cores, pollen, tree rings, etc. (Lackner et al. 2012). Greenhouse effect keeps the earth warm enough to hold life by absorbing and re-emitting the infrared radiation by means of various greenhouse gases such as water vapour, carbon dioxide (CO_2), methane, nitrous oxide, ozone, etc., else the earth would be 33 °C colder than the present (Karl and Trenberth 2003; Lackner et al. 2012). CO_2 is the most important greenhouse gas, due to its higher concentration in the atmosphere as compared to others (Lackner et al. 2012), and its concentration increased rapidly from the pre-industrial levels of 280 ppm (Penuelas et al. 2013; Hui et al. 2017) to 408.53 ppm as on October 2019 (CO_2 Earth, https://www.co2.earth/). Atmospheric concentration of CO_2 is expected to rise up to 486–1000 ppm, based on the differences in model scenarios (Lindner et al. 2010; Hui et al. 2017). The mean temperature of Earth's surface has already risen by 0.8–1.2 °C above pre-industrial levels since 1900 due to various human activities and is expected to reach 1.5 °C between 2030 and 2052, if it continues to increase at the current rate and no mitigation measure is taken (Inter-governmental Panel on Climate Change (IPCC) 2013). Such a trend in global warming has brought about significant alterations in global climate.

Anthropogenic activities, such as deforestation, land-use changes, burning of fossil fuels, etc. have led to climate change at a greater pace resulting in various catastrophes including flood, draught, forest fire, etc. Evidence for climate change has already been documented with a rise in sea level, decrease in Arctic ice, decrease in snow cover, increase in the intensity and frequency of extreme events, warming of oceans, etc. (National Aeronautics and Space Administration (NASA), http://climate.nasa.gov/evidence/; Dantas-Torres 2015). World's all ecological and economic systems are dependent upon climate and change in climate induces uncertainty on the stability of these systems (IPCC 2014; Steiner et al. 2018). Climate change has the tendency to cause enormous loss of biodiversity, slowing evolutionary potential and disrupt ecological services (Dawson et al. 2011). Although climate change would affect various regions of the world with varied intensity, Asia is known to be one of the most vulnerable regions due to its large land cover and dense population (Akram 2012; Bhuiyan et al. 2018). Moreover, as biodiversity is much concentrated in the developing countries, these nations become much vulnerable to climate change as they suffer from biodiversity, ecosystem, and resource losses (eco-biological aspects) on one hand, and less affordability to mitigation and adaptation costs (socio-economic aspects) on the other. At this critical juncture, the role of forests in mitigating climate change is immense, as they help to overcome the overwhelming eco-biological and socio-economic impacts of climate change. Different forest types and biomes in different regions respond to climate change in different ways and they also differ in their ability to sustain the livelihoods of people dependent on them. Since biodiversity and ecosystem services largely contribute to the socio-economic sector as well, this review focusses mainly on the eco-biological impacts of climate change and the role of different forest biomes towards climate change mitigation.

2 Eco-Biological Impacts of Climate Change

The impacts of climate change on eco-biological aspects could vary across different ecosystems based on their type, location, composition, resilience, structural attributes, etc. Understanding the core eco-biological impacts of climate change is thus the primary step towards planning and implementing climate change mitigation and adaptation measures (Scheffers et al. 2016).

2.1 Loss of Biodiversity and Ecosystem Services

Biodiversity is considered as an important indicator of Earth's health (Reed 2012) and helps in providing ecosystem services as well as boosts nation's economy. Various ecosystem services rendered by natural ecosystems can be broadly classified into four categories: (i) supporting services (primary productivity, nutrient cycling, pollination, seed dispersal, soil formation, etc.), (ii) regulating services (nutrient retention, climate regulation, air and water purification, flood control, etc.), (iii) provisioning services (providing food, timber, wood products, non-timber forest produce, medicine, etc.) and (iv) cultural services (having cultural, aesthetic values, educational services, etc.) (Reed 2012). Climate change impact on biodiversity affects humans in several ways from a local to a global scale. There is a unanimous consensus that climate change has already caused a significant loss of biodiversity and thereby disrupted the chain of ecosystem services and economic goods. Although natural ecosystems are endowed with the ability to recover from a disturbance and resume their ecological functions, the loss in biodiversity that is being witnessed in recent time due to climate change might not be reversible. Hence, many species (both aquatic and terrestrial) are facing the dire possibility of extinction, if appropriate interventions are not made. Under the on-going pace of climate change, coupled with anthropogenic disturbances, the earth is likely to undergo sixth mass extinction in the next 240 years (Barnosky et al. 2011; Hooper et al. 2012; Pravalie 2018). It has been predicted that approximately 10% of the species may extinct with every 1.0 °C rise in temperature (Benton and Twitchett 2003; Mayhew et al. 2008; Reed 2012). Around 20–30% of flora and fauna are expected to become extinct, in the event of a temperature rise of 2–3 °C above pre-industrial levels (Fischlin et al. 2007) and under the scenario of mid-range climatic warming, 15–37% of species are likely to be 'committed to extinction' by 2050 (Mooney et al. 2009). Approximately

150 bird species have already become extinct in the last 500 years (Mooney et al. 2009; Bhattarai 2017) and the extinction rate of the endemic species could rise up to 39–43%, under worst-possible scenarios, which in turn indicates that around 56,000 plant and 3700 vertebrate species might get lost (Malcolm et al. 2006; Rinawati et al. 2013). The rate of extinction has been estimated to be greater than 100 species per million species per year (Rockstrom et al. 2009; Pravalie 2018). As of now, the extinction rate has been estimated to be greater than 100 species per million species per year (Rockstrom et al. 2009; Pravalie 2018). In come cases, a phenomenon called “extinction debt” occurs, where functional extinction of a species precedes the actual physical extinction of the species (Pecl et al. 2017). With the extinction of species, the ecosystem regulating services become disrupted and this could in turn, create a positive feedback to climate change.

Climate plays a crucial role in regulating the distribution of populations and in structuring the biological communities (Austin and van Niel 2011; Drielsma et al. 2017). Therefore, it is expected that changes in the temperature and precipitation regimes would affect species’ traits, vegetation structure, and composition, ecological and physiological processes across different vegetation types, land uses and regions (Niu 2001; Lindner et al. 2010; Gao et al. 2016). Change in temperature influences the insulating nature of the snow, which in turn alters the soil temperature by determining the extent of exposure of soil to the cold air, which may alter the composition of soil biota (Edwards et al. 2007; Rogora et al. 2018). An alteration in climate is known to decouple plant-pollinator interactions via several ways (Hegland et al. 2009; Ramirez and Kallarackal 2018), thus affecting both pollinator diversity as well as plant diversity. On the other hand, reduced pollinator diversity could result in poor fruit-setting and regeneration potential of plants. This scenario is further complicated in the case of those plant species that have obligate/specialist pollinators (Gilman et al. 2011; Ramirez and Kallarackal 2018). Climate change also lowers genetic diversity due to directional selection, genetic drift as well as population migration (Rinawati et al. 2013). Since biodiversity is the fundamental unit of all ecosystem processes and is also easily vulnerable to extinction due to climatic alteration, it is imperative to understand the effects of different drivers of climate change, both individually and synergistically to take proper conservation measures.

Freshwater ecosystems are particularly vulnerable and endangered ecosystems as they are the fragmented habitats and therefore freshwater species have limited ability to disperse (Woodward et al. 2010; Bhattarai 2017). Climate change-related drivers are altering the community structures of freshwater ecosystems and it is further exacerbated by eutrophication, characterized by algal blooming and hypoxia (Pesce et al. 2018). Freshwater ecosystems are also affected by stresses such as extraction and exploitation of resources, pollution, etc. due to their closeness to human habitations (Woodward et al. 2010; Bhattarai 2017). On the other hand, increasing temperature of the oceans, ocean acidification, inundation of estuarine ecosystems by sea water, rise in sea level, changes in coastline etc. are some of the drivers that bring about compositional and community changes in marine ecosystems, subsequently leading to the disruption of their ecosystem services (Day et al. 2008; Ackerly et al. 2012; Asmus et al 2017). Coral reefs act as natural protection against huge ocean and tidal waves (Ninawe et al. 2018). The complex coral reef ecosystems are projected to decline on a large scale by 2050 (Baker et al. 2008; Bhattarai 2017). Mangrove forests are known to respond to climate change by landward migration, which poses a threat to other coastal habitats like salt marshes (Satyanarayana et al. 2013; Bhattarai 2017). It has been predicted that there would be a reduction in mangrove forests for about 10–20% by 2100 (Danovaro et al. 2008; Bhattarai 2017). Hence, biodiversity and ecosystem services would continue to be impacted and impaired for several years to come because of climate change.

2.2 Range Shifts

Biogeographic range expansions or contractions occur due to the increase or decrease in the climatically suitable areas (Jackson and Overpeck 2000; Garcia et al. 2014) and such range shift is a means of an evolutionary, adaptive strategy for survival of organisms (Pitelka 1997; Drielsma et al. 2017). The most basic and often observed response to global warming and climate change is upslope and poleward shifts in species' habitat ranges (Parmesan et al. 1999; Hannah and Bird 2018) and species tend to undergo long-distance latitudinal shifts towards the poles when upslope movements were constrained by other factors or not possible. The species in the northern hemisphere move northwards and those in the southern hemisphere move southwards (Hannah and Bird 2018). It has been estimated that terrestrial taxa shift towards pole at the rate of 17 km per decade, while marine taxa move at the rate of 72 km per decade (Sorte et al. 2010; Poloczanska et al. 2013; Pecl et al. 2017). Lower altitude species are shifting upwards to higher elevations and the higher altitude species are constantly restructuring their community relationships (Woodward et al. 2010; Bhattarai 2017). Biogeographic range shifts also occur during stable climatic conditions, where organisms migrate in search of food, water and other resources based on their physiological needs (Pitelka 1997). Species that cannot adapt in the changing climatic conditions and require wet and cool habitats undergo range contractions and finally become extinct (Thomas et al. 2004; Drielsma et al. 2017). With increasing anthropogenic disturbances, climate change favours weedy and opportunistic species, whereas, those that are niche specific become trapped (Hannah and Bird 2018). The ability of a species to shift its range to a new location depends on timely availability of a new environment with enough resources that would support the species' establishment (Pitelka 1997; Hoegh-Guldberg et al. 2008; Drielsma et al. 2017). Further, a species' ability to shift its range in response to climate change depends on their ecological and evolutionary characteristics (Dawson et al. 2011; Bhattarai 2017). However, establishing new populations at the leading edge of the range expansion in new habitats tend to lead to genetic bottlenecks over time, potentially lowering the adaptive ability of the population to future climate change scenario (Nei et al. 1975). On the other hand, range contractions also lower genetic diversity and are likely to face extinction (Rubidge et al. 2012; Staudinger et al. 2012). Furthermore, interspecific hybridization may allow a species to persist in a changing climate, which leads to lower species diversity and affects the ecosystem functioning to a large extent (Seehausen et al. 2008; Edwards et al. 2011; Staudinger et al. 2012).

2.3 Changes in Phenology

Climate change leads to significant phenological changes in temporal biological events such as flowering and fruiting as it is closely linked with climate (Penuelas and Filella 2009). Most phenological changes occur due to changes in temperature, which critically influence the timings of leaf flushing, budding, migration of populations, nesting, egg-laying, breeding, etc. (Hannah and Bird 2018). Various life-cycle processes depend on seasonal and inter-annual variations in the climate (Parmesan and Yohe 2003; Visser and Both 2005; Scheffers et al. 2016) and such changes in phenology are evidenced in several flora and fauna around the world, although the regions in high latitudes as well as altitudes exhibited changes on a large-scale (Canadell and Mooney 2002). Forests and other vegetation types of around 54% of the Earth's terrestrial surface have shown a significant alteration in phenology from 1981 to 2012 (Buitenwerf et al. 2015; Pravalie 2018). However, phenological changes due to climate change is not uniform in all vegetation types as carbon dioxide enrichment induced early flowering in forb species, but delayed the same in grass species (Cleland et al. 2006; Mooney et al. 2009). Plant-pollinator interactions become greatly disrupted due to climate change and changes in the phenology of both plants and pollinators results in the timing mismatches (Memmott et al. 2007; Ackerly et al. 2012; Rinawati et al. 2013). It has been reported that several plant species have underwent flowering much early in the last 20–50 years due to increase in temperatures, early snowmelt, altered precipitation regimes, etc. (Fitter and Fitter 2002). At the same time, the period of emergence of the insect pollinators has also changed drastically over the years due to changes in climate (Weiss et al. 1988; Weiss and Weiss 1998; Ackerly et al. 2012). Mismatches in phenology have been observed in between annual plants and butterflies, where the annual host plants die much before the insect larvae enter the diapause (Parmesan et al. 2013; Scheffers et al. 2016). These changes also result in physiological changes, thereby, largely alter species' distribution patterns and their abundance (Canadell and Mooney 2002; Bhuiyan et al. 2018).

2.4 Drought and Forest Fires

A pronounced impact of climate change that is slowly spreading out across the globe, is the desertification caused by superheating and failed rainfall (Abrams et al. 2018). Droughts are characterized by a clear sky, high temperature and low humidity (Corlett 2018). Water stress imposes severe pressure on forest ecosystems, especially drylands that cover approximately 45% of the Earth's land area (Schimel 2010;

Pravalie 2018). Extremely severe droughts have the potential to cause mortality in huge trees, possibly due to hydraulic failure (hindering water transport through xylem by forming air bubbles) and carbon starvation (due to the closing of stomata) (Corlett 2018). Effects of short-term drought are reversible, provided normal rainfall prevails in the subsequent years. However, multiple, and long-term droughts can have severe and irreversible consequences. It leads to altered species composition, with drought-tolerant species being favoured more (Corlett 2018).

The synergistic effect of high temperature and drought increases fuel loads for forest fires and thus, the fire frequency (Kasischke and Turetsky 2006; Pecl et al. 2017). Often, the prevalence of dry atmospheric conditions and adequate fuel loads, especially in regions with semi-arid and sub-humid climatic conditions, act as the main trigger for forest fire (Pravalie 2018). Natural forest fires play a crucial role in maintaining the horizontal and vertical structures of the forest, nutrient cycling, plant diversity, etc. (Thonicke et al. 2001; Hurteau et al. 2014; de la Barrera et al. 2018) and therefore mediates several ecological processes. However, when natural fire regime gets altered due to climate change and global warming, the consequences are often drastic. A forest fire not only alters ecosystem functions and releases the stored carbon dioxide, but also emits particulate matter (Price et al. 2012; de la Barrera et al. 2018), detrimental to both biodiversity and proximal human habitations. Fires in Amazonia lead to the loss of 12–30% of the live aboveground biomass, 23–31% of canopy cover and caused 226–462% of the tree mortality (Brando et al. 2014; Pravalie 2018). Aerosol particles emitted from the forest fires tend to scatter the incoming solar radiation and therefore affect the uplifting of water vapour (Tosca et al. 2010; Ellison et al. 2017). Besides, the black carbon aerosol particles, when accumulated on ice and snow decreases albedo and increase the air temperature (Randerson et al. 2006; Pravalie 2018). Megafires cause tremendous loss to both life and property, besides affecting ecosystem services (Hurteau et al. 2014; de la Barrera et al. 2018). In the case of prevalence of an intermediate level of rainfall, forest fire acts as a strong predictor of the spatial distribution of forests and savannahs as the presence of forest fire leads to open canopies and savannahs, while the absence of a forest fire leads to closed canopies and the expansion of forest tree cover (Pravalie 2018). Since it is expected that climate change would increase drought and desertification, there exists a high risk for the occurrence of forest fires in the future.

2.5 Disease Outbreaks

Climate change remains a big threat to forest ecosystems by causing drought stress to plants and greater surviving potential to insects during winter, due to increased temperatures (Raffa et al. 2008; Grimm et al. 2013). The innate resistance of trees to defend itself against the pest or pathogenic attack is lessened due to drought stress (Kurz et al. 2008; Brecka et al. 2018). Disease outbreaks due to insects are very high in boreal forests because the lifecycles of insects have been extended in these high latitude ecosystems due to global warming, affecting trees in the growing season

(Trumbore et al. 2015; Pravalie 2018). While many insects cause damage during the growing season by defoliation, the mountain pine beetle (*Dendroctonus ponderosae*) is known to kill trees (and therefore destroy several hectares of forests) by feeding on the phloem and therefore curtailing the trees' nutrient supply (Brown et al. 2010; Hicke et al. 2012; Pravalie 2018). Other infamous insect pests which kill huge forest areas are the Aspen leaf miner (*Phyllocnistis populiella*), leaf blotch miner (*Micrurapteryx salicifoliella*), southern pine beetle (*Dendroctonus frontalis*), Janet's looper (*Nepytia janetae*), spruce beetle (*Dendroctonus rufipennis*), etc. (Bebber et al. 2013; Scheffers et al. 2016). The disease-causing plant pathogen and pest species have moved poleward at the rate of 2–3.5 km per year since 1960s (Altizer et al. 2013; Scheffers et al. 2016).

The increase in heat waves, decrease in air and water qualities, extreme climatic events like flooding, etc. could trigger the geographic expansion of vector-borne diseases and hence, high mortality among humans (Hernández-Delgado 2015; Abrams et al. 2018). It has been projected that disease-causing pests and their vectors like mosquitoes, ticks, and pathogens such as bacteria and fungi could be carried off via desert dust (or dry sand particles) to long distances, where they were previously absent (Reiter 2001; Hernández-Delgado 2015). *Anopheles* mosquito that causes malaria, a highly prevalent disease is now migrating upward and poleward (Siraj et al. 2014; Pecl et al. 2017). Therefore, the disease outbreak impact of climate change among forests and humans remains as one of the major challenges.

2.6 Impacts on Agriculture

There is a strong linkage between climate change, agriculture and nutrition threatening not only the agricultural sector, but also the associated livestock productivity (Fanzo et al. 2018). Climate change, besides lowering crop yields also lowers the nutritional quality of the crops produced (Myers et al. 2014; Morris et al. 2017). Decline in crop yields might not be globally uniform as the hotter countries are likely to be at a greater risk (Morris et al. 2017). Climate change is expected to cause dry areas to become drier and wet areas to become wetter and such an increase in water stress and heat stress (Cheung et al. 2010; Fanzo et al. 2018) would invariably affect crop yields and crop nutritional values. Since agricultural lands are intensively pressurized for increased yields due to monocropping, excess use of fertilizers and pesticides, etc., a decline has been observed in the soil quality, which would in turn affect the productivity and nutritional value (Fanzo et al. 2018). Desynchronization of plant-pollinator interactions and decreasing trends in faunal diversity also drastically impair agricultural production. (Intergovernmental Platform on Biodiversity and Ecosystem Services 2016; Ramirez and Kallarackal 2018). To counteract the decreasing agricultural yields of major crops like wheat, genetical alterations are currently being used by crossing the domesticated crops with wild strains (Hamilton and Miller 2016; Scheffers et al. 2016). However, the ability of the newly produced genetically modified crops to withstand the effects of climate change and their potential impact on human health requires further investigation.

2.7 Extreme Weather Events

As climate alteration becomes more and more pronounced, there could be a drastic change in temperature and rainfall regimes, affecting several ecosystem services. This sudden and rapid alteration in basic ecosystem services might be very difficult for humans and wild plants and animals to cope up with (Abrams et al. 2018). Alteration in temperature and precipitation regimes would result in the incidence of intense and frequent extreme weather events. Global warming would affect the season, duration and amount of precipitation, rate and season of snowmelt, snowpack volume, streamflow, and temperature (Hamlet et al. 2005; Clifton et al. 2018).

A change in precipitation pattern would ultimately affect vegetation distribution and growth (Adams et al. 2012) and an increase in temperature along with intense precipitation would bring about more frequent extreme hydrologic events (Hamlet et al. 2013; Clifton et al. 2018). River flow alterations would also affect other abiotic characteristics such as water temperature, water quality, sediment transport, etc. and cause changes in the magnitudes of evaporation and precipitation (Poff and Zimmerman 2010; Doll and Zhang 2010;). High amounts of precipitation would significantly cause turbidity due to increased runoff and lower the water transparency to ultraviolet radiation, and thereby, the ability to get disinfected, affecting the health of a wide range of life forms—from zooplanktons to humans (Connelly et al. 2007; Overholt et al. 2012; Grimm et al. 2013). Increased flooding because of increased precipitation may cross the threshold retention potential of ecosystems. Consequently, a flash export of sediments, contaminants, dissolved organic matter, disease-causing organisms, etc. are carried away to long distances, creating further havoc (Grimm et al. 2013). Such a scenario would result in the restructuring of biota and habitats (Staudinger et al. 2012).

It has been estimated that since 1901, the global sea levels have already risen for about 20 cm and it might rise for another 30 cm by 2100 (Corlett 2018). Increased temperatures may also lead to the drying of rivers and streams, collapsing the food webs and ecological stability (Sabo et al. 2010; Grimm et al. 2013). Another important consequence of global warming is the increase in the intensity and frequency of tropical cyclones, which play a crucial role in shaping the species composition and structure of the tropical forests, especially rainforests in Caribbean, Central America, Madagascar, southeast Asia, northeast Australia and oceanic islands like Fiji and Mauritius (Corlett and Primack 2011; Corlett 2018). Moreover, a dramatic change in winter temperatures and winter snow cover may cause cold injury, altered water and energy balance, advance, or slow down the phenological responses (variable according to species) and alter the community interactions (Williams et al. 2015). Unusual extreme events may occur at the beginning of winter before organisms have accumulated the programmed physiological protection, which could lead to damage (Henry 2008; Williams et al. 2015). Mid-winter melts may alter soil temperature due to exposure and thereby affect soil flora and fauna and such melts also lead to the encasement of ice crystals and cause anoxia (Coulson et al. 2000; Williams et al. 2015). Early ice breakups also affect and cause mortality in higher organisms like polar bears by shortening the length of the winter-feeding season and lengthening the summer fasting season (Regehr et al. 2007; Williams et al. 2015).

3 Other Exacerbatory Factors

3.1 Deforestation

Deforestation is one of the main anthropogenic factors that exacerbate the effects of global warming and climate change. It is defined as "forest clearance and subsequent conversion to another land-use, which means the permanent loss of forest cover (Food and Agriculture Organization (FAO) 2013; Pravalie 2018). Deforestation, although prevalent worldwide, is predominant in the tropics, where about 100 Mha were cleared between 2000 and 2012, of which 50, 30 and 20% were in Latin America, southeast Asia and Africa respectively (Hansen et al. 2013; Keenan et al. 2015; Kim et al. 2015; Mitchard 2018). The causes for deforestation vary by location: mining and large-scale agriculture in Latin America, plantations of palm-oil, pulp and paper in Southeast Asia and small-scale agriculture, mining, plantations, etc. in Africa (Zarin et al. 2016; Mitchard 2018). Deforestation has several severe ecological and economic implications such as reduction in the regional rainfall and increasing the risk of forest fires leading to further drying and dying of forest flora and fauna (Rinawati et al. 2013). Deforestation not only damage the felled trees, but also causes collateral damage to the neighbouring trees (de Andrade et al. 2017). It is the main cause of intense water erosion in Africa (Pravalie 2018). Deforestation significantly contributes to global climate change via two principal mechanisms: by emitting to carbon dioxide and by causing radiative cooling by increasing the surface albedo (Bala et al. 2007; van der Werf et al. 2009; Lee et al. 2011; Pravalie 2018).

3.2 Habitat Fragmentation

Intact forest ecosystems offer better services than the disturbed ones. In this context, habitat fragmentation is a serious ecological threat to climate change due to lowering biodiversity, altering ecosystem functions, making the ecosystems more vulnerable to forest fires, pest attacks, etc. Fragmentation of habitats affects species dispersal and migration patterns; the effects are more pronounced in forest edges than in the core fragments (MacArthur and Wilson 1967; Kappelle et al. 1999).

The edge effects make the edge species to become more vulnerable to biotic and abiotic perturbations (Laurance et al. 2007; Pravalie 2018). Further, altered environmental conditions results in high temperature, wind, vapour pressure deficit and availability of light, nutrients, and other resources (Matlack 1993; Reinmann and Hutyra 2017). Habitat fragmentation limits nutrient flow and connectivity and interaction of species across two or more ecosystems (Billings and Gaydess 2008; Auffret et al. 2015; Pravalie 2018).According to Jenkins (1992), if the habitat fragmentation rates are very high, terrestrial and protected areas are akin to isolated "ecological islands" that are surrounded by "oceans" of altered habitats leading to gradual loss of biodiversity and augmenting species extinctions which destabilizes the ecosystem integrity (Myers 1979; Jenkins 1992; Kappelle et al. 1999). However, the effects depend on several factors such as size of the forest fragments, species characteristics, species interactions and nature of the surrounding habitat (Gibson et al. 2013; Estrada et al. 2017; Pravalie 2018). As a result of loss in home ranges of top carnivores due to forest fragmentation, there occurs a total collapse of the entire trophic level, severely impairing ecosystem functioning (Dobson et al. 2006; Mooney et al. 2009). Fragmented patches of forests tend to become drier and are susceptible to forest fires (Corlett 2018). Thus, habitat fragmentation is clearly an important factor that not only advances climate change via several mechanisms, but also impacts the ecosystem functioning and services.

3.3 Land-Use Change

Land-use change is another one of the important factors for climate change and is expected to increase in the coming future, due to increasing demands for agricultural and biofuel production, migration of human populations, etc. (Corlett 2018). Land-use change virtually affects almost all kinds of ecosystem services, especially the regulating and provisioning services (Abrams et al. 2018). Land-use changes have already altered several ecosystem services like nutrient cycling, water regulation, timber production, carbon sequestration, etc. (Bhattarai 2017). Land-use change to agricultural or urban systems drives many species to extinction, at least regionally (Pravalie 2018). It also results in the loss of massive amounts of carbon that was previously accrued in different carbon pools for a long time (Naudts et al. 2016; Pravalie 2018). Studies envisaged that due to land use changes, forest area has been reduced by one-third and with concommitment emission of about 146 Pg C back to the atmosphere, since 1850 (Williams 2006; Reinmann and Hutyra 2017). Moreover, it has led to widespread habitat fragmentation due to which 20% of the world's forest cover now lies within 100 m of a forest's edge (Haddad et al. 2015; Reinmann and Hutyra 2017). Land-use changes contribute to global climate change in two ways: biogeochemical effects (such as the absorption and release of greenhouse gases like carbon dioxide) and biophysical effects (such as alterations in the surface energy budget) (Schimel et al. 2001; Iordan et al. 2018). Major biophysical effects are the change in surface albedo (Iordan et al. 2018) and the global radiation balance by causing changes in the emissions of biogenic compounds, which could possibly affect the patterns of cloud formation, bringing about great changes in the climate albedo (Unger2014; Iordan et al. 2018). Therefore, land-use change is widely considered as an exacerbatory factor of concern that contributes to both regional as well as global climate change.

3.4 Biological Invasion

Biological invasion is one other important manifestation of global warming and climate change. Climate change is known to favour the expansion of invasive species (Ackerly et al. 2012) and in turn, invasive species also exacerbates the effects of global warming in many ways by contributing to the fuel loads for forest fire, hindering the nutrient cycles and biogeochemical processes, etc. Climate change creates novel optimum habitats for the successful establishment of invasive species, facilitating the process of invasion (Bradley et al. 2009; Shrestha et al. 2018). Invasive species are more tolerant to a wide range of climatic conditions and have unique biological traits that enhance their competitive success (Sundarapandian et al. 2015; Sundarapandian and Subashree 2017). Around one-sixth of the terrestrial part of the globe is highly vulnerable to alien species invasion (Early et al. 2016; Lamsal et al. 2018). With increasing impacts of climate change, invasive species are developing several kinds of adaptations to enhance their populations (Clements and Ditommaso 2011; Lamsal et al. 2018). As a result of range shifts, species that were previously unknown to be invasive may likely become invasive and threaten the native biota in the newly colonized habitats. Of late, woody plants have invaded the high-latitude ecosystems that were mostly herb-dominated (Sturm et al. 2001; Grimm et al. 2013). Similarly, alien invasive species are now found to have been distributed along the lower and mid-elevations of mountain ecosystems and they might soon occupy high elevations too (Alexander et al. 2016; Lamsal et al. 2018). Thus, alien species invasion could dramatically alter the species composition and community structure of the invaded habitats and drastically alter the ecosystem functioning.

4 Socio-economic Aspects: A Cross-Link

Climate change not only exerts eco-biological impacts, but also has socio-economic implications as well and together they exercise a greater bearing than influence caused individually (Audsley et al. 2015). These impacts are expected more severe in developing countries than developed countries due to idiosyncrasies in geographical location (Morton 2007; Savo et al. 2018). These factors may be: the importance of agriculture and other climate-sensitive sectors in their economies, greater exposure to extreme events, warmer baseline climatic conditions, increased population growth (Parry et al. 2001; Fischer et al. 2005; Cline 2007; Esperón-Rodríguez et al. 2016), lack of development to modern technology, inadequate and unequal access to resources, political conflicts, etc. The effects of climate change would be disproportionate as poor people would be more vulnerable and they have less adaptive capacity (Swart et al. 2003). However, poor people also contribute to climate change as in many instances, poor farmers convert forests and marginal lands to agricultural farms or plantations and they use inefficient technologies (Swart et al. 2003). At the same time, farmers would be seriously affected by crop failures as well as shifting patterns of the disease vectors (Morris et al. 2017). Moreover, increases in carbon dioxide is known to have lowered the nutritional value in commercially important crops such as rice, wheat, peas, soy and potatoes (Fanzo et al. 2018). This has a dual impact as on one hand, the market values of these crops are affected and on the other, the consuming population becomes undernourished. Socio-economic development and climate change are intimately tied with each other as the former would certainly lead to greenhouse gas emissions. At the same time, the impacts of climate change on agriculture, fisheries, etc. would also severely impede socio-economic development (Swart et al. 2003). Climate change would also greatly stress the forestry sector, which has a significant economic role, by causing decrease in wood quality, thereby affecting the market prices of timber (Hisano et al. 2018). Furthermore, climatic variability, alteration in air quality, prevalence of heat waves, spreading of vector-borne diseases, etc. may also seriously affect human health (Swart et al. 2003). Lack of water supply or the availability of poor quality of water may lead to sanitation issues as well (Fanzo et al. 2018). Therefore, the impacts of climate change affect socio-economic development and vice versa and the effects are more pronounced on the poor and the developing world. Increasing droughts and erratic precipitation cause failure in crops is leading to modern day slavery in south East Asian countries.

5 Role of Forests in Climate Change Mitigation

Spanning more than 4.1×10^9 ha, forests constitute the dominant terrestrial ecosystems on our planet (Dixon et al. 1994; Pan et al. 2013; Hui et al. 2017). Besides performing various ecosystem functions, forests act as refugia for several species (Allen et al. 2010; Hui et al. 2017) and contribute on a large-scale to climate change mitigation in a multitude of ways, both regionally and globally. Tropical forests alone are known to harbor 50% of the 5–20 million species of plants and animals on Earth (Lewis et al. 2015; Pravalie 2018). Forests are known to mitigate climate change and global warming by a process called evaporative cooling (cooling of air due to high rates of evapotranspiration), by altering the land's surface radiation balance (via albedo effect) as well as carbon sequestration (Lewis et al. 2015; Pravalie 2018). Forests play a crucial role in maintaining the atmospheric moisture and regulation of rainfall patterns. The release of water vapour from the terrestrial surfaces are mediated by forest vegetation by means of evapotranspiration, thus resulting in atmospheric moisture (Aldrich and Imberger 2013; Debortoli et al. 2016; Ellison et al. 2017). Such moisture-laden clouds are circulated by winds across different regions (Ellison et al. 2017). Forest trees and other vegetation are also known to intensify rainfall by the emission of certain biological particles (fungal spores, bacterial cells, pollen grains, etc.). Atmospheric moisture condenses when the air is well-saturated with water and it condenses more readily if suitable surfaces are present, which are provided by aerosol particles that are referred to as condensation nuclei (Sheil 2014; Ellison et al. 2017). Furthermore, it has been reported that individual trees have the capability to transpire hundreds of litres of water every single day using solar energy and due to the presence of deep roots, trees can maintain their cooling effect even during intense and long-lasting heat waves (Ellison et al. 2017). Forest trees also contribute to increased water infiltration by means of its deep roots (Espeland and Kettenring 2018).

Forests also help in limiting pollution levels by capturing the particulate pollutant matter on the leaf surface (Chiabai et al. 2018). Since forests are rich in biodiversity, the presence of one species is known to influence the presence of several other species via its ecological functions. It has been observed that some species facilitate other species to cope up with climate change. Synergistically (and also via the 'domino effect'), highly biodiverse forest slows down the pace of global climate change and exhibit increased resilience (Bruno et al. 2003; Espeland and Kettenring 2018). Forests also offer several other ecosystem services buffering the effects of climate change by preventing water-based and wind-based erosion, shading the vegetation in the lower storeys, maintaining soil moisture by litter accumulation, etc. (Espeland and Kettenring 2018). Plants are also known to reduce the speed, height and the impact of cyclones and storms, which tend to causing flash flooding (Hu et al. 2015; Espeland and Kettenring 2018).

6 Carbon Sequestration

Forests play a critical role in mitigating climate change because they act as huge storehouses of carbon due to their unique ability to remove carbon continually from the atmosphere (Goers et al. 2012). The ability of forests to act as sink for atmospheric carbon dioxide has been widely recognized as a major mechanism of mitigating climate change. Forests are estimated to store approximately 45% of the terrestrial carbon and account for around 50% of the terrestrial net primary production (Bonan 2008; Anderegg et al. 2012; Pravalie 2018).

Plant photosynthesis is the primary mechanism by which forest ecosystems draw in large amounts of carbon from the atmosphere (Waring and Running 2007; Lorenz and Lal 2010). Trees absorb atmospheric carbon dioxide and fix it in their biomass of stems, leaves, branches and roots. When the branches and leaves fall as litter and decompose, some of the stored carbon gets released into the atmosphere through respiration, while another part seeps into the soil. Therefore, the net carbon balance, also referred to as the net ecosystem productivity, is the total carbon accumulated by the forest ecosystem in its various carbon pools, subtracted by the amounts of carbon lost due to microbial respiration, soil respiration, mortality, etc. (Hui et al. 2017). Different carbon pools are living biomass (of both trees and understorey vegetation), dead biomass (detritus and litter), soil (on-site carbon pools) and wood products (off-site carbon pool) (Bettinger et al. 2017). Carbon is represented as 45–50% of the dry vegetation biomass (Birdsey 1992; Bettinger et al. 2017). Vegetation biomass is considered a major carbon pool as the sequestered carbon of forest vegetation amounts to around 359 billion tonnes (Allen et al. 2010; Hui et al. 2017). Soil is also another important huge carbon pool consisting of approximately 2344 Pg C in the top 3 m (Jobbagy and Jackson 2000). According to United Nations Framework Convention on Climate Change (UNFCCC 2010), around 283, 38 and 317 Gt of carbon are stored in biomass, deadwood and litter plus soils (top 30 cm) respectively (Fiorese and Guariso 2013). As per the report of FAO (2015), 296 Gt of carbon are contained in biomass alone in all of the world's forests (Guo and Gong 2017). These figures highlight the immense ability of forests to sequester atmospheric carbon.

As reported by Lorenz and Lal (2010), carbon sequestration occurs in forest ecosystems mainly when (i) the total organic carbon of a forest (inclusive of all the carbon pools) increases in a specified time interval by absorbing atmospheric carbon dioxide and (ii) the pool of organic compounds present in the vegetation, detritus and soil of a forest vegetation contain long carbon residence time that increases over time. However, climate change has a profound influential role in global carbon cycling. Therefore, a forest ecosystem may function either as a sink or a source depending upon its environmental conditions. Climate change could stimulate photosynthesis due to increased carbon dioxide concentration in the atmosphere (carbon fertilization) might favour biomass accumulation, in which case the forest may function as a net carbon sink. On the other hand, warmer temperatures can enhance the rates of microbial and soil respiration processes, in which case, the forest may act as a carbon sources. Therefore, a forest's role in carbon sequestration (a source or a sink) is determined by the difference between the gross primary productivity and ecosystem respiration (Field et al. 2007; Hui et al. 2017). However, although forests function as carbon sinks due to carbon fertilization, Mooney et al. (2009) suggest that their absorptive capacity is getting saturated and they may hence switch their role from sinks to sources by the end of this century.

Carbon cycling, which is a crucial regulatory cycle of forests, is being controlled by various environmental drivers. Some of those drivers are temperature, precipitation, nitrogen deposition, atmospheric carbon dioxide concentration, soil quality, soil nutrients, soil moisture, etc. (Beedlow et al. 2004; Kets et al. 2010; de Vries et al. 2017). As many regions in the warmer world are likely to become drought-prone, water deficits would possibly lead to tree mortality, either directly by carbon starvation and hydraulic failure or indirectly by increasing the vulnerability to insect and pest attacks (McDowell et al. 2008; Hisano et al. 2018). Even without water deficits, tree longevity is expected to be reduced and trees may compete severely for resources (Luo and Chen 2015; Hisano et al. 2018). Carbon cycling is also adversely influenced by other factors such as the loss of forest canopy cover, intense solar radiation, surface water run-off, etc. (Anderegg et al. 2012; Pravalie 2018). The influence of and the interactions among the drivers may be synergistic or antagonistic (Zavaleta et al. 2003; de Vries et al. 2017), creating profound changes in ecosystem carbon fluxes. Whatsoever be the hindering factor, the net result is mostly always a loss in biomass and the release of carbon back into the atmosphere (Lewis et al. 2011; Hisano et al. 2018). The release of carbon that is stored in the vegetation and soil would in turn, increase the atmospheric carbon dioxide concentration and accelerate the pace of global warming and climate change (Rinawati et al. 2013).

In order to mitigate carbon emissions by forests, four main steps were proposed: (i) increasing the forested land area by means of reforestation, (ii) increasing the carbon density at both stand and landscape levels of existing forests by adopting proper strategies such as maintaining reduced disturbances and lengthened harvest cycles (iii) increasing the usage of forest products in a sustainable fashion to minimize the emissions due to combustion of fossil fuels and (iv) reducing the emissions due to deforestation and forest degradation (Canadell and Raupach 2008). Forest carbon sequestration could also be enhanced by implementing several important measures like reducing the forest conversion to other land-uses, adopting appropriate silvicultural practices that would enhance growth, preventing biomass loss due to natural and anthropogenic processes, etc. (Sedjo 2001; Guo and Gong 2017). Therefore, it is evident that carbon sequestration is an incredible regulatory ecosystemservice rendered by forests all over the world and adopting appropriate measures would enhance their mitigation potential.

7 Carbon Storage and Climate Change Response of Major Forest Biomes

Food and Agriculture Organization (2000) defines a forest as "a land with tree cover (at least 5 m high) of at least 0.5 ha, and a canopy cover of more than 10%" (Pravalie 2018). The world's forests span around 42 million square kilometers, which cover around 30% of the Earth's terrestrial surface (Bonan 2008; Keenan et al. 2015; Pravalie 2018). The world's forests are principally classified into three major biomes, viz. tropical, temperate and boreal based on latitudinal location, climatic factors such as temperature and precipitation and eco-physiology (Dixon et al. 1994; Woodward et al. 2004; Lorenz and Lal 2010; Pan et al. 2013; Hui et al. 2017). Most of the world's forests are located in Asia (31%), followed by South America (21%), North America (17%), Africa (17%), Europe (9%) and Oceania (5%) and together, they hold about 861 Pg C, of which approximately 383 Pg C lie in soil, 363 Pg C in live biomass, 73 Pg C in deadwood and 43 Pg C in litter (Pan et al. 2013). According to Dixon et al. (1994), the world's forests contain around 1150 Gt C, of which tropical forests account for 37%, while temperate and boreal forests account for 14% and 49% respectively (Malhi et al. 1999). Climate change drastically influences the forest structure and functioning, including that of the carbon cycle, which in turn provides a feedback (mostly positive) to climate change.

7.1 Tropical Forests

Tropical forests are well-known for their rich species diversity and high productivity. Tropical forests are located between 23° N and 23° S of the Equator (Hui et al. 2017). On the whole, tropical forests cover around 20 million square kilometres, which is roughly 50% of the world's forested land (Pan et al. 2011).The average temperature is 20–25 °C and the annual rainfall is about >2000 mm. Tropical forests are characterized by tall trees (25–35 m), with many hardwood species that contribute on a large-scale to carbon sequestration in their multistoried profiles (Hui et al. 2017).The tropical forests are broadly classed into four types based on precipitation, degree of seasonality as well as elevation: (i) ever-wet (or rainforest), (ii) semi-evergreen, (iii) dry deciduous and (iv) montane forest types (Meister et al. 2012). Tropical forests are known to hold about 25% of the global terrestrial biosphere's carbon and they contribute to 33% of the terrestrial net primary productivity (Sabine et al. 2004; Bonan 2008). According to Malhi et al. (1998), about 8% of the terrestrial atmospheric carbon dioxide is cycled in tropical forests (Meister et al. 2012).

Several researchers have provided varying estimates on the biomass and carbon stocks of tropical forests around the world. This is so because, different tropical forest types across regions allocate biomass in different patterns due to varying environmental conditions, stand structure and vegetation composition (Meister et al. 2012). According to Soepadmo (1993), tropical forests contain 428 Gt of carbon, of which 58% is stored in vegetation, 41% in soil and 1% in litter (Watson et al. 2000; Meister et al. 2012). Reichstein (2007), estimated that these forest biomes likely store 206–389 Pg C in vegetation and 214–435 Pg C in soil, up to a depth of 1 m (Lorenz and Lal 2010). Pan et al. (2011) estimated that tropical forests contain about 471 Pg C, which accounts for 55% of the carbon stored in world's forests. Also, they pointed out that tropical forests store 56% of carbon in vegetation biomass and 32% in soil. The reason for less carbon stocks in soil is the rapid decomposition of dead matter under the warm and humid conditions that prevails in the tropical forests and the minerals rapidly leach out of the soils (Gorte 2007; Hui et al. 2017). Saatchi et al. (2011) estimated that tropical forests stocked 247 Gt C in vegetation biomass, of which 193 Gt C was aboveground and 54 Gt C was belowground. Tropical forests of Latin America accounted for 49% of the total carbon stock of world, followed by those in Southeast Asia (26%) Saharan Africa (25%). However, according to Sullivan et al. (2017), the highest carbon density of tropical forests in Asia (197 Mg C/ha), followed by Africa (183 Mg C/ha) and South America (140 Mg C/ha). Nevertheless, tropical forests are known to account for about 60% of the global photosynthesis, thereby sequestering around 72 Pg C every year, they also roughly release same amounts of carbon via respiration by plants, microbes and animals (Beer et al. 2010; Mitchard 2018).

Tropical forests of Southeast Asia and the Amazon are expected to suffer from droughts, especially during El Nino Southern Oscillation events. Although they could withstand short-term droughts, become more susceptible to forest fires, both after short-term and long-term droughts (Meister et al. 2012). The severity of the effects of the drought varies depending on the forest type and water availability (Meister et al. 2012; Hisano et al. 2018). In the event of drought, when tropical forest soils become dry, not only carbon dioxide gets released, but also methane, another important greenhouse gas (Cattanio et al. 2002; Meister et al. 2012). Moreover, when vegetation dries out, human-induced fires could spread and engulf large-portion of the tropical forest landscape creating widespread damage. Since both photosynthesis and respiration of plants are directly tied to temperature, water availability, sunlight, atmospheric carbon dioxide concentration, oxygen, etc., climatic alterations would have pronounced effects on these primary metabolic pathways. If the carbon uptake is increased by photosynthesis, hence will result in increased productivity. This happens because of greater carbon fertilization. In such case, the forest trees might eventually attain a point of saturation and become constrained due to limitation in some other resource(s) (Phillips et al. 2008; Meister et al. 2012). Further, with a rise in temperature, respiration increases leading to more release of carbon, while the rate of photosynthesis remains at the threshold level (Meister et al. 2012). Consequently, they may switch over their functioning from being 'sinks' to 'sources'. When the plants reach this saturation point, litter production also levels off, which would cause changes in the soil biotic communities, influencing soil respiration as well, that would cause further soil carbon losses (Coley 1998; Meister et al. 2012).

In general, tropical forests exert a strong control over climate change (Pravalie 2018) by acting as large carbon reservoirs. In addition, they also alleviate climate change by means of evaporative cooling and cloud formation (which reflects the incident radiation back to space) (Bonan 2008; Jackson et al. 2008; Pravalie 2018). Tropical forests could become vulnerable to a warmer climate which in turn accelerate the pace of global warming via a positive feedback that would lessen the evaporative cooling, increase the amounts of carbon dioxide released back to the atmosphere and gradually begin forest dieback (Betts et al. 2004; Bonan 2008; Malhi et al. 2008). Nonetheless, tropical forests do occupy an important place in mitigating global climate change due to its huge carbon sequestration ability.

7.2 Temperate Forests

Temperate forests cover approximately 8 million square kilometres and occur between 25–60° N and 25–55° S latitudes, accounting approximately for 20% of the world's forests (Pan et al. 2011; Hui et al. 2017; Pravalie 2018). Most of these forests lie in the Northern Hemisphere, whose southern limit is just a little above the Tropic of Capricorn (Tyrrell et al. 2012). These forests experience a clearly manifested seasonality in the climate, with warm summers alternating with cold winters (Reich and Bolstad 2001; Lorenz and Lal 2010). The temperature in temperate forests ranges between −30 and 30 °C and the precipitation ranges from 500 mm to 1500 mm (Martin et al. 2001; Lorenz and Lal 2010; Tyrrell et al. 2012). These forests are less diverse than tropical forests, but more diverse than boreal forests (Lorenz and Lal 2010; Hui et al. 2017). Although temperate forests have less diversity, they are prominently recognized to possess some of the world's tallest trees like *Sequoia sempervirens* (Pan et al. 2013; Pravalie 2018).

Temperate forests occupy a prominent place in the global carbon cycle, although it is the smallest of all the three discussed forest biomes (Reich and Bolstad 2001; Lorenz and Lal 2010) as they account for approximately 13.8% of the terrestrial carbon sink (Robinson 2007). As per Dixon et al. (1994), temperate forests store 59 Gt C in vegetation and 100 Gt C in soil. Temperate forests contain 109 Pg C in aboveground biomass and 49 Pg C in belowground biomass (Robinson 2007). Overall, it has been estimated that temperate forests store 73–159 Pg C in vegetation and 153–195 Pg C in soil up to a depth of 1 m (Robinson 2007; Lorenz and Lal 2010). According to Bonan (2008), temperate forests account for 20% of the global vegetation biomass and 10% of the terrestrial carbon. Pan et al. (2011) estimated that temperate forests contain about 119 Pg C, which is 14% of the carbon stored in world's forests. Temperate forests act as an important carbon sink as they sequester about 0.2–0.4 Pg C every year and they are known to have high productivity and high resilience in the event of a disturbance (Tyrrell et al. 2012). The major carbon sequestering pool in temperate forests is the tree biomass, although the other biomass pools such as understorey, detritus and litter also contribute substantially (Whittaker and Woodwell 1986; Son et al. 2001; Peichl and Arain 2006; Dar and Sundarapandian 2015). Tree species composition greatly influences the carbon storage potential of temperate forests and typically, biomass and carbon accumulation increases with stand age (Chen et al. 2011; Wei et al. 2013; Dar and Sundarapandian 2015). The carbon storage is usually low in younger stands and high in older stands due to longer period of biomass accumulation and the older stands usually hold two to five times more carbon than the younger stands (Pregitzer and Euskirchen 2004; Peichl and Arain 2006; Tyrrell et al. 2012). The carbon pools of temperate forests are strongly regulated by stand age, size class of trees, elevation, forest composition, etc. (Pregitzer and Euskirchen 2004; Wang et al. 2014; Dar et al. 2017).

Photosynthesis is the main mechanism that essentially regulates the carbon uptake by trees and the optimum temperature for photosynthesis in temperate forests is 5–20 °C, which usually occurs during spring (Malhi et al. 1999; Tyrrell et al. 2012). Temperate forests show an increase in annual productivity due to increase in spring temperatures, caused due to global warming (Saigusa et al. 2008; Tyrrell et al. 2012). In case of occurrence of severe and recurrent droughts during summer, there would be tree mortality, resulting in carbon loss (Breda et al. 2006; Lorenz and Lal 2010). Water availability is a crucial determinant of carbon stocks as it exerts control over tree growth as well as tree species distribution (Hinckley et al. 1981; Tyrrell et al. 2012). Water deficit and therefore drought stress, in the presence of elevated carbon dioxide concentration could significantly alter the process of gas exchange and reduce the tree growth (Tschaplinski et al. 1995; Tyrrell et al. 2012), by causing stomatal closure and hindering carbon uptake (Hinckley et al. 1981; Jarvis 1989). Therefore, at least on the short-term drought stress is likely to have a negative impact on regional carbon budgets. However, Beerling et al. (1996) stated that the trees are likely to develop drought tolerance in the future, thereby leading to little impact of drought on the net ecosystem productivity (Tyrrell et al. 2012).

A warmer world has increased soil temperature, which would greatly alter the rates of decomposition and soil respiration. High summer temperatures are expected to enhance ecosystem respiration processes by increasing soil temperatures (Yuan et al. 2008; Zhu et al. 2009; Tyrrell et al. 2012). In toto, the carbon cycle in temperate forests is predominantly influenced by length of the growing season, cloud cover, snow depth in winter and the extent of drought in summer. While the former two factors strongly influence photosynthesis, the latter two factors regulate decomposition and respiration (Goulden et al. 1996; Tyrrell et al. 2012). It has been projected that high temperatures and high amounts of precipitation would bring about increases in soil and microbial respiration processes and therefore, increase in carbon emissions (Tyrrell et al. 2012).

Most temperate forests are also severely impacted by wind disturbances and high-velocity ice storms (Dale et al. 2001; Tyrrell et al. 2012). Small- to intermediate-levels of disturbances are likely to result in either gap formation or gap expansion and young slender trees die before attaining maturity (Worrall et al. 2005). Therefore, there would be a decline in the overall regional carbon sequestration as only very few young stands manage to develop into mature stands (Uriate and Papaik 2007; Tyrrell et al. 2012). Moreover, such wind- and ice storms could cause injuries to trees from branch breakages to severe tree mortality, depending on the local site conditions, storm intensity and species involved (Bragg et al. 2003; Tyrrell et al. 2012). In the event of such disturbances, carbon gets quickly transferred from living biomass pool to dead biomass pool and gradually gets decomposed (Uriate and Papaik 2007; Tyrrell et al. 2012), resulting in rapid loss of stored carbon. Apart from the above responses of temperate forests to climate change, the tropospheric ozone concentrations also could cause a drastic reduction in the carbon sequestration potential by causing foliar injuries, reduced tree growth and hence lowering the above- and belowground productivity (Augustaitis and Bytnerowicz 2008; Wittig et al. 2009; Lorenz and Lal 2010). Therefore, various environmental components and climatic events profoundly influence the carbon cycling in temperate forests.

Despite the above, the climate change consequences in the temperate forests are projected to be less severe than the other major forest biomes (Lorenz and Lal 2010). This has been attributed that temperate forests currently exist on a stable balance due to its relatively stable forest cover, successional patterns and age-class distribution (Tyrrell et al. 2012). However, this balance is very fragile and small changes in forest cover or age-class distribution could shift the temperate forest ecosystems from carbon sinks to either carbon-neutral or carbon-releasing ecosystems (Tyrrell et al. 2012).

7.3 Boreal Forests

The boreal forest biome is the world's second largest biome, which provides a wide range of ecosystem services, the most important of which is the timber supply (Astrup et al. 2018). These are located between 50 and 60° N and covering an area of about 1.2 billion hectares, constituting about 30% of the most globally densely forested area (Crowther et al. 2015; Hui et al. 2017; Brecka et al. 2018). The boreal forest biome is the youngest of all the major forest biomes and it has about 48% of the world's relatively undisturbed forest (Bryant et al. 1997; Taggart and Cross 2009; Lorenz and Lal 2010). The mean annual temperature in this biome ranges from −10 to 5 °C and the annual precipitation is usually less than 500 mm and is mainly in the form of snow (Hui et al. 2017; Pravalie 2018). They are characterized by short and moderately warm summers, and long and cold winters (Hui et al. 2017), as a result, the tree growth rate is very low due to the short growing season (Kellomaki 2000; Brecka et al. 2018). With poor tree diversity (Pravalie 2018), they are distinguished by the presence of spiral canopies (Landsberg and Gower 1997; Lorenz and Lal 2010). Another major feature of this biome is that soils are very deeply frozen by permafrost, hampering both root development and soil water drainage (Camill 2005; Lorenz and Lal 2010).

Boreal forest biome is known to contain highest amount of carbon than the tropical and temperate forest biomes and it contributes largely to the terrestrial carbon sink (Denman et al. 2007; Bonan 2008; Hui et al. 2017). However, the boreal forest biome holds only the second largest quantity of carbon, next to the tropical forest biome (Pan et al. 2011; Astrup et al. 2018). The rates of decomposition is very slow due to short summers (Hui et al. 2017), which enhances the soil carbon sink. It has been estimated that around 84% of the boreal forest carbon lies in the soils and only less than one-sixth occurs in the vegetation biomass (Hui et al. 2017). As per Dixon et al. (1994), boreal forests store 88 Gt C in vegetation and 471 Gt C in soil. In general, boreal forests are expected to hold between 78 and 143 Pg C in vegetation and roughly around 338 Pg C in soils, up to a depth of 1 m (Robinson 2007). Around 42 Pg C and 15 Pg C are stored in the aboveground biomass and belowground biomass of boreal forests (Lorenz and Lal 2010). Pan et al. (2011) estimated that boreal forests contain about 272 Pg C, which accounts for 32% of the carbon stored in world's forests.

Lichens and bryophytes are particularly important in the boreal forest biome because they play an important role in the boreal forest carbon cycle by influencing carbon storage as well as release. Lichen and bryophyte tissues form a dense mat in the ground layer of boreal forests and these tissues decompose more slowly than the fallen woody debris (Turetsky 2003; Milakovsky et al. 2012). Also, thick mats of mosses can limit the heat gained from the atmosphere (Startsev et al. 2007). On the other hand, when they dry out, they may act as fuel loads for forest fires, due to their flammability (Harden et al. 1997). Fire plays an important role in the boreal forest biome as it is responsible for transferring huge amounts of carbon from vegetation biomass to the soil by converting into charcoal that is decay-resistant and can stay for about 3000–12,000 years in the soil (DeLuca and Aplet 2008; Milakovsky et al. 2012).

Boreal forest biome are experiencing greater rates of global warming than any other forest on Earth (Gauthier et al. 2015; Astrup et al. 2018). It has been expected that the environmental conditions in the warming world would significantly alter the photosynthetic and respiration processes, thereby affecting the carbon balance of boreal forests (Milakovsky et al. 2012). The type of vegetation in boreal forests strongly influences the respiration process by determining the quality of litter produced (Harden et al. 2000; Milakovsky et al. 2012). A rise in soil temperatures due to global warming is expected to increase the rates of decomposition and respiration, although it is also possible that these processes proceed in slower rates, owing to shifts in the microbial communities, caused by soil warming (Allison and Treseder 2008; Milakovsky et al. 2012). Fire also alters the soil characteristics by causing changes in soil temperature and soil moisture, by reducing or removing the insulating lichen and moss layers, etc. Fire also contributes to carbon sequestration by contributing huge amounts of charcoal to the soil carbon pool (Milakovsky et al. 2012). However, increase in temperatures as a consequence of global warming could lead to increases in thaw depth in those areas covered by permafrost, thus accelerating microbial decomposition and releasing large amounts of two important greenhouse gases, viz. carbon and methane (Leigh 2009) that had been accrued for several centuries. Higher temperatures would facilitate the widespread occurrence of fires with increased frequency and severity across the boreal forest biome (Stocks 2004; Lorenz and Lal 2010).

Increase in atmospheric carbon dioxide concentrations generally stimulates plant growth and carbon accumulation by carbon fertilization and this is often seen as a means of offsetting the carbon losses caused due to wildfires (Balshi et al. 2007; Milakovsky et al. 2012). A mild drought affects only the respiration process, while a severe drought impedes both photosynthesis and respiration (Barr et al. 2007; Milakovsky et al. 2012). Any change in water balance would affect carbon uptake more severely in high latitude ecosystems than high temperatures (Lorenz and Lal 2010). If the climate change causes warm temperatures in early spring, forest productivity would increase enhancing the biomass and carbon stocks (Chen et al. 1999). However, if temperatures increase at the fag end of the growing season, moisture stress could be an important problem, where the increase in growth would be outdone by increase in respiration and may/may not be coupled with decrease in photosynthesis (Lindroth et al. 1998; Milakovsky et al. 2012). Therefore, whether precipitation increases or decreases along, with the rise in temperature, there would be strong influences on the carbon flux (Pastor and Post 1988; Milakovsky et al. 2012). Furthermore, it has been predicted that future warming would surpass the optimum photosynthetic temperatures of several boreal tree species (Way and Sage 2008; Lorenz and Lal 2010). Drought affected regions are more susceptible to pest and insect outbreaks, which would enhance the rates of tree mortality and thereby release of the stored carbon (Frey et al. 2004). Apart from wildfires and drought stress, boreal forests are also greatly affected by extreme weather events like windstorms that cause uprooting of trees, which would in turn lead to drastic changes in the forest community dynamics (Ulanova 2000; Lorenz and Lal 2010) and carbon removal.

A main response of boreal forests to climate change and global warming is its expansion northward and into the tundra biome, while temperate forests simultaneously invade its southern border (Milakovsky et al. 2012). A steady movement of boreal forests northward has been observed (Brecka et al. 2018) because of which the tundra biome is likely to lose 50% of its areal extent. Also, the on-going climate change could result in the loss of evergreen species replaced by deciduous tree species (Bonan 2008). The expansion of boreal forests into the tundra biome would mean that there is an increased risk of forest fires in tundra region (Kasischke et al. 1995). The northward expansion of boreal forest biome would result in treeline changes, causing changes in albedo in the northernmost latitudes. Although albedo neither causes carbon storage or release directly, it highly influences the amount of heat absorbed by the biome (Milakovsky et al. 2012). Expansion and extension of tree cover in boreal forests would decrease the surface albedo and increase the warming in boreal forests (Bonan 2008). Therefore, by way of expansion, boreal forests would cause climatic warming on both regional and global scales, which may outstrip their role as carbon sinks (Betts 2000; Milakovsky et al. 2012).

8 Climate Change Mitigation: Steps Taken so Far

Climate change has grabbed the attention of scientists since 1820s and since then, the strategies to combat climate change in the form of adaptation and mitigation has been formulated (Stein et al. 2013; Bhattarai 2017). The United Nations Conference on Environment and Development held on June1992 at Rio de Janeiro, Brazil, addressed a broad spectrum of issues related to climate change, biodiversity, etc. and led to the establishment of United Nations Framework Convention on Climate Change (UNFCCC) (Raufer and Iyer 2012) in 1994 leading to the Conference of Parties (CoP) meet every year. The adoption of the Kyoto Protocol (1997), which entered into force on 2005 recognizes the critical role that the forests play in reducing the emissions of carbon dioxide (Bettinger et al. 2017) and focusses on regulating major six greenhouse gases.

The Kyoto Protocol recognizes three flexibility mechanisms for the countries to meet their emission targets, viz., Joint Implementation (JI; Article 6), Clean Development Mechanism (CDM; Article 12) and International Emissions Trading (IET; Article 17). CDM and JI are together known as 'project-based mechanisms'related to emission reductions from projects. In the case of IET, the Annex I parties (which include developed countries and countries with economy in transition) allowed to trade their emissions, otherwise referred as Assigned Amount Units (AAUs). Emission Reduction Units (ERUs) from another Annex I country via emission-reduction or emission-removal projects. The CDM enables the Non-Annex I parties (developing countries) to earn Certified Emission Reduction (CER) credits, each equivalent to one tonne of carbon dioxide. Aside from the above mechanisms, voluntary carbon markets have also played an important role in climate change mitigation. Voluntary carbon markets were created outside of regulation by governments by firms and individuals, who buy carbon offsets voluntarily to reduce their production of greenhouse gases (Shahbol et al. 2018).

The negotiation of a legal binding, The Paris Agreement at CoP-21 was a very significant step towards climate change mitigation, which came effective since November 2016. The agreement's main aimed to keep a global temperature rise this century well below 2 °C and to drive efforts to limit the temperature increase even further to 1.5 °C above pre-industrial levels. The Article 5 of the Paris Agreement stresses on the crucial role of forests in mitigating the emission of greenhouse gases (Bettinger et al. 2017; Mitchard 2018). All the countries individually determined and submitted their Intended National Determined Contributions (INDCs), which later became National Determined Contributions (NDCs), with the ratification of the Paris Agreement (Grassi et al. 2012, 2017). Later, the CoP-23 witnessed many important developments such as 'Ministerial on Climate Action' by China, 'Powering Past Coal Alliance' by UK and Canada, Talanoa dialogue, etc.

Besides this, the Asia Pacific Partnership on Clean Development and Climate was signed by the United States, Canada, Australia, India, China, South Korea and Japan in 2005, which together account for about 50% of the global greenhouse gas emissions. The main objective of this partnership was to work together with private sectors towards achieving their goals on energy security, reduction of air pollution as well as climate change via methods that would support sustainable development of their national economies and curb poverty (Raufer and Iyer 2012). Emphasizing on the significance of climate change, IPCC has so far published five assessment reports and is now in the process of producing the sixth report based on the assessments of their three working groups and a Task Force. IPCC's global scientific authority published a new report on October 8, 2018 stating that the Earth's temperature would warm 1.5 °C above pre-industrial levels by 2030 leading to the increased incidence of extreme droughts, floods, wildfires, and widespread food shortages.

Recognizing the crucial role of forests in climate change mitigation, an initiative of UNFCCC called Reduced Emissions from Deforestation and forest Degradation (REDD) was framed in 2008 to provide economic incentives to the forest-rich developing countries to help in carbon sequestration (Kishwan et al. 2009; Sheikh et al. 2011). Later, it was extended as REDD+ to include conservation of forests, sustainable forest management and enhancement of carbon stocks and succeed in reducing emissions from deforestation and forest degradation (Bettinger et al. 2017). To emphasize the forestry sector, the New York Declaration on Forests signed by 192 organizations (inclusive of 40 governments) in 2014 to reduce the rate of loss of natural forests globally by 2020, strive to end natural forest loss by 2030 and to restore the currently deforested or degraded land with in stipulated time frame (Mitchard 2018). Also, the process of forest certification (green certification) has also gained prominence in the recent decades, which is related with the assesses and certifies the quality of forest management as per predetermined factors to promotes enhanced forest management and protection schemes due to sustainable usage (Bettinger et al. 2017). With more awareness on climate change and its impacts caused due to increased levels of greenhouse gases, the calculation of carbon footprints has gained significant attention in the last few years.

9 Climate Change and Its Mitigation: Indian Scenario

India is regarded as one of the 17 megadiverse countries (Mittermeier et al. 1997) and harbors four of the biodiversity hotspots (Himalaya, Indo-Burma, Sundaland, Western Ghats), three megacentres (Eastern Himalaya, Western Ghats and Western Himalaya) and 25 microcentres of endemic flora and fauna (Nayar 1996) The wide range of climatic and topographic conditions support a broad range of habitat types and hence, biodiversity (Rodgers et al. 2002; Reddy et al. 2017). The Indian forests has been classified into four major groups and 16 type groups: *tropical* (wet evergreen, semi-evergreen, moist deciduous, littoral and swamp, dry deciduous, thorn, dry evergreen), *sub-tropical* (broad leaved hill forests, pine, dry evergreen), *temperate* (montane wet, Himalayan moist temperate, Himalayan dry temperate) and *alpine* (sub-alpine, moist alpine, dry alpine scrub) forests (Champion and Seth 1968; Ramachandra et al. 2015). India ranks tenth in terms of forest cover (21.54% in geographical region) (FAO 2015) and second most populous country (17.5% of the world's population) in the world (Reddy et al. 2015). India with its rich biological and forest wealth on one hand and inflating population on the other is likely to be adversely affected on both the eco-biological and the socio-economic fronts due to climate change. This is evident by increase in mean annual temperature by 0.5 °C during 1901–2003 primarily in northern India, which experienced a steeper rise in the maximum temperature (1983–2003) as compared to the southern region (Dash and Hunt 2007; Melkania 2009). It has been estimated that the temperature could arise between 3.5 and 5.5 °C by 2100 (Kumar and Chopra 2009). The change in temperature has led to shifts in the location of various forests types. For example, the forests in the northeast are shifting towards wetter forest types, while those in the northwest are shifting towards drier forest types, provided there is no human interference (Ravindranath et al. 2006; Melkania 2009). The Himalayan region, which has a major influence over climate on most of the North India is supposed to be one of the most vulnerable regions to climate change (Xu et al. 2009; Maiti et al. 2017). The alternation in the climate has been influencing the Himalayan glaciers severely impacting the water supply, agriculture, energy sector, etc. of the regions traversed by major rivers in India. It has been projected that Himalayan glaciers would shrink to a mere 1,00,000 km^2 by 2030, with the current rates of global warming (Kumar 2005; Kumar and Chopra 2009). The rapid melt of glaciers would cause rivers to swell up during monsoons leading to flooding and the water level would fall to low levels during summers causing water shortage (Bajracharya et al. 2007; Kumar and Chopra 2009). The fact that the wet seasons are likely to become wetter and the dry seasons are likely to become drier in India, would affect the seasonal cycle of plants and animals, and cause the spread of vector-borne diseases (Kumar and Chopra 2009). There are also evidences of shifting of many species upward seeking cooler climates in the Himalayas region (Mishra and Singh 2017; Singh et al. 2012). The altered monsoon patterns coupled with the incidence of droughts had already hit hard at the agricultural sector, which forms the backbone of Indian economy. The deltaic regions and major food-producing states have suffered huge losses due to climate change and global warming. Moreover, the states along the coastlines are highly vulnerable to cyclones and in the future may require remapping of boundaries as the low-lying coastal regions are at a risk of getting submerged due to rise in sea level. Ocean warming and ocean acidification have drastically affected the fish diversity, distribution, and phenology (Ninawe et al. 2018), thereby impacting the fishery sector. In addition, the ocean acidification would affect the calciferous animals and cause mass coral bleaching. The Indian coral reefs have undergone 29 mass bleaching events since 1989 due to ocean warming (Ninawe et al. 2018). Aside from the natural impacts on climate change on the eco-biological and the economic spheres, the anthropogenic pressures such as deforestation, dumping of wastes, urbanization, etc. are pushing the natural ecosystems beyond their natural capacities to adapt and recover.

According to the Emissions Database for Global Atmospheric Research (EDGAR) (http://edgar.jrc.ec.europa.eu/), India ranks third among countries with highest carbon dioxide emissions. However, India is also recognized for its vast forest cover and therefore has a huge potential for carbon storage. India, together with Myanmar and Indonesia accounts for 70% of the carbon stocks of Asian forests (Brown et al. 1993; FAO 2010; Rajashekar et al. 2018). The carbon stock of Indian forests is 7082 million tonnes (FSI 2017). Of these, 2238 million tonnes are stored in aboveground biomass and 699 million tonnes are locked in belowground biomass in the vegetation pool, which are primarily located in Arunachal Pradesh, Madhya Pradesh, Chhattisgarh and Maharashtra.

India has played its part towards combating climate change by planning and implementing various measures. India acceded to the Kyoto Protocol on 26th August 2002 and has also ratified the Paris Agreement (October 2016) and signed the Asia Pacific Partnership on Clean Development and Climate in 2005. National CDM Authority provides guidelines and regulations regarding the CDM projects implemented in India. India ranks second (after China) based on the number of CERs issued as on 31st August 2018 (CDM Project activities, https://cdm.unfccc.int). Many of the CDM projects in India are focused on wind energy, electricity generation, waste handling and disposal, establishing green buildings, etc. National Action Plan on Climate Change in June 2008, included eight core national missions related with solar, enhanced energy efficiency, sustainable habitat, water sustaining the Himalayan ecosystem, green India, sustainable agriculture, and strategic knowledge for climate change. State action plans on climate change were also implemented in several states across India. India has also established Coal Cess and the National Clean Energy Fund as well as National Adaptation Fund for Climate Change towards climate change mitigation. Broadly, India has undertaken several initiatives in different sectors like energy, transport, agriculture, industry, forestry, etc. towards meeting the objectives of UNFCCC (Ministry of Environment, Forests and Climate Change, http://envfor.nic.in).

10 Climate Change Mitigation: The Way Forward

Effective climate change mitigation requires constant planning, implementation, and assessments to protect the biodiversity from going extinction, even on a local scale. An ecosystem that is species-rich offers more and better ecosystem services than the one which is species-poor. Therefore, conservation planning is a very critical step towards climate change mitigation and it must consider the environmental factors, phenologies, patterns of species distribution, species interactions and other ecological processes that govern a species' vulnerability to extinction (Monzon et al. 2011; Staudinger et al. 2013). Usage of computational mathematical models would better enable in predicting novel climates and biological responses (Hannah and Bird 2018), which would pave way for better biodiversity conservation. (and other climatic studies demand a great attention. Assisted colonization or assisted migration, where species with poor dispersal abilities are intentionally moved out of their historic ranges to new areas that would be climatically suitable under climate change scenarios may save them from extinction (Hoegh-Guldberg et al. 2008; Pravalie 2018). Connectivity corridors prevent local extinctions and help alleviate the effects of habitat fragmentation (Damschen et al. 2006; Pravalie 2018). Afforestation and reforestation on abandoned and degraded lands may increase local species richness, besides offering considerable ecosystem benefits. In areas that are prone to flooding, fast-growing and high-water consuming tree species are the better choice to reduce the flood risk. In contrast, areas that suffer drought could be planted with slow-growing and less water-consuming tree species to increase the infiltration (Ellison et al. 2017). In general, mixed species forests tend to be healthier and more productive than monocultures as the presence of different species with different requirements helps in aiding each other in water absorption, nutrient uptake, erosion control, etc. and are more resilient in the face of climate change (Reubens et al. 2007; Paquette and Messier 2011;Ordonez et al. 2014; Pretzsch et al. 2014; Ellison et al. 2017).

Aside from protecting biodiversity by the above measures, the life cycle assessments of greenhouse gases would help in better framing of policies and evaluation of options aimed towards climate change mitigation (Reijnders 2012). It is also essential to abruptly halt the deforestation of old-growth forests and limit land-use changes to minimize the pressures on forest ecosystems (Koh and Ghazoul 2010; Lambin and Meyfroidt 2011; Reed 2012). Development of novel cleaner energy technologies and implementation of the existing technologies (Pacala and Socolow 2004; Reed 2012) would lessen the effects of pollution and lower the burden on fossil fuels. More so, energy conservation would provide natural ecosystems adequate time to generate the natural resources and prevent them from being over-exploited. Following appropriate agricultural practices such as enhancing the efficiency of the nitrogen fertilizers applied (to decrease the emissions of nitrous oxide), improving the soil quality and enhancing soil carbon sequestration by modifying the tillage practices, developing drought-resistant varieties, etc. would also help in climate change mitigation (Swart et al. 2003). Proper management of freshwater resources by improvising the water supply and storage facilities, promoting efficient water-use (Swart et al. 2003) and interlinking of rivers could help overcome water deficits. Another important concern that needs to be addressed is the lack of awareness on the importance of biodiversity and the impacts of climate change among people, especially in the rural areas (Reed 2012). It therefore becomes necessary to reach out to those people and spread awareness, to curtail the rates of factors that exacerbate climate change like deforestation, land conversion, etc. People in rural and remote locations are the victims of climate change. Hence, apart from educating them, proper measures are needed to provide them with access to water, nutritious food, healthcare, and modern eco-friendly technologies. Thus, climate change could be mitigated effectively by synergistic implementation of various measures and people participation.

11 Conclusion

Climate change is a very pressing issue as it exerts a great deal of eco-biological and socio-economic impacts on almost all the sectors of any nation. An efficient climate change mitigation strategy would be to increase the resilience of forest ecosystems and biodiversity to climate change. At this critical juncture, carbon sequestration by forest ecosystems is of immense importance in climate change mitigation. Understanding the crucial roles of different forest biomes and the various ecological processes operating therein would help in framing management strategies that would enhance their carbon sequestration potential. At the same time, it is also necessary to cut back on the various anthropogenic pressures placed on the forests. However, a country's development inevitably places pressures on forest ecosystems. Therefore, adoption of sustainable utilization of resources and energy and resource conservation practices would help climate change mitigation in the long run. Although several important measures have already been taken by international bodies like UNFCCC, periodic reviewing on the effectiveness of the undertaken measures and devising of new strategies in accordance with the climate change-induced alterations in scenarios are essential. However, the effectiveness of the outcomes of climate change mitigation projects depends on the availability of funding as well as the flexibility and feasibility of mechanisms.

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Climate Change Impact on Eco-biology and Socio-economy—A Concise Discussion

Subhankar Chatterjee and Ankit Tandon

Abstract Global scientific community has a near unanimous consensus that anthropogenic emission of greenhouse gases and thus their rising atmospheric concentration are causing global warming and other climatic changes. According to the IPCC, global average annual mean surface air-temperature is projected to rise between 1.4 and 5.8 °C by 2100. This rise in temperature will impose various climate related incidents like drought, forest fires, typhoons, more intense hurricanes, and frequent storms. Due to the decrease in air quality, human health related problems in future will be catastrophic. Considering the present climate trend, climate scientists are speculating that new ecosystems will be emerged and existing ecosystems will be wiped out in future and this shift in biomes will be irreversible. The multivariate factors of climate change are supposed to have an effect on all the levels of biodiversity, starting from organism to biome levels. Not only ecosystem destruction but also climate migration is a major issue at present because this migration is directly impacting the socio-economic profile of many countries. Many governmental and non-governmental organisations have predicted that a billion people may be displaced by 2050 as a result of environmental causes, and climate change will be one of the major contributors. It has been found that people are less bothered about climate change and this issue is in their lowest priority list as people think they are not personally responsible for climate change and has seen climate change as a global effect. Ignorance and greed of the people sometimes leads them to violate the natural/environmental rules and as a result negative consequences of climate change are the obvious outcomes of these unethical activities.

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1 Climate Change—A Myth, Hype or a Reality?

Climate change refers to significant and lasting changes in the statistical distribution of weather parameters, e.g. in air temperature, precipitation, wind patterns etc. In a much simpler view, "climate change" refers to any change of the classical 30-year climatology, regardless of its causes. According to Inter-governmental Panel on Climate Change (IPCC), often "climate change" denotes only those variations caused by human activities, whereas, changes due to natural variations are referred "climate variations" (IPCC 1995). Global scientific community has a near unanimous consensus that anthropogenic emission of greenhouse gases and thus their rising atmospheric concentration are causing global warming and other climatic changes. According to the IPCC, global average annual mean surface air-temperature is projected to rise between 1.4 and 5.8 °C by 2100, based upon the findings of leading modelling groups around the world (IPCC 2001). Studies carried out over the past two decades elucidated that Earth's climate will change in response to accrual of greenhouse gases in the lower atmosphere. The unusually rapid temperature rise since the mid-1970s to the tune of 0.5 °C is considerably attributable to this anthropogenic rise in the concentration of greenhouse gases (IPCC 2001; Trenberth 2001). We have already seen various effects of this recent warming on non-human systems (Easterling et al. 2000; Malhi and Phillips 2004; Parmesan and Yohe 2003; Rignot et al. 2003; Root et al. 2003; Thompson et al. 2002; White et al. 2005). Due to very long residence time of greenhouse gases in lower atmosphere, the climate system's inertia, climate change would continue for at least several decades even if radical preventative actions are taken now (Houghton 2004; IPCC 2001). There has been a debate about the present quantum and future trajectories for anthropogenic emissions of greenhouse gases. It is obvious that there are uncertainties about the sensitivity of the climate system to future changes because atmospheric composition of these greenhouse gases (normally present in the atmosphere) is in parts per million or parts per billion fractional (volume) concentration levels. The range in the predicted rise in global average annual mean surface air temperature (1.4–5.8 °C) by 2100 indicates both uncertainty about future emissions of greenhouse gases and marginal differences in design of the several leading global climate models. The spatial distribution pattern of projected temperature and particularly change of rainfall also differ between these integrated/coupled global climate models. Therefore, reported estimates of climate changes over coming decades are indicative rather than predictive (IPCC 2001). It is worthy to mention here that the uncertainty is symmetrical. So, an underestimation of future climate change is as likely as an overestimation. It can be stated with considerable confidence that in longer-term, the probability of exceeding critical thresholds i.e. causing sheer-changes in climate, environment and related effects will definitely rise (Houghton 2004; IPCC 2001).

2 Climate Change and Air Quality

Weather, instantaneous state of atmosphere, defined in terms of parameters viz. air temperature, relative humidity, wind regime, and mixing height (the vertical height of mixing in the atmosphere) and thus climate i.e. average weather over a region play important roles in determining patterns of air quality over multiple temporal and spatial scales (Kinney 2008). These connections can drive through alteration in emission, transportation, dilution, chemical transformation, and ultimately dry and wet deposition of air pollutants (Younger et al. 2008). There is growing concern that development of most favourable control strategies for key pollutants like ozone and fine particles demands proper assessment of potential future climatic conditions and their influence on the achievement of air quality parameters (Bernard et al. 2001). When framing policies to improve air quality and human health, meteorological variables are usually taking into account. To determine when, where, and how to control pollution emissions, it is assumed that weather reported in the past is a good proxy for weather that will occur in the future (Bransford and Lai 2002).

Air-quality and climate have strong coupling (linear/non-linear). Most of the sources of air pollutants also emit carbon dioxide, other Green House Gases, and/or particulate matter that affect local, regional or global climate (Fiore et al. 2015). These air pollutants interact with solar and terrestrial radiation and perturb the Earth's energy balance, leading to changes in regional or global climate (IPCC 2013). Climate change influences air-quality by changing the frequency, severity, and duration of heat waves, air stagnation events, precipitation, and other meteorology conducive to pollutant accumulation (Jacob and Winner 2009; Weaver et al. 2009; Ordóñez et al. 2005; Tressol et al. 2008; Vieno et al. 2010).

It has been well established that the meteorology over a region influences the air quality substantially. Patterns of air pollution concentrations in a specific region are governed by this climate alteration. Increase in air temperature could speed-up the thermo-chemical reactions that led to the formation of tropospheric ozone and secondary aerosols. Under higher temperature and elevated carbon dioxide concentrations regime, vegetation emits more amounts of ozone-relevant Volatile Organic Carbon precursors (Hogrefe et al. 2005). Studies examining empirical statistical relationships between meteorological parameters and observed ozone concentrations have shown that higher temperatures typically result in increased simulated ozone concentrations (Gaza 1998; Lin and Fiore 2001; Ordóñez et al. 2005; Vukovich 1995). Using an integrated Global Climate modelling approach, when future ozone projections were examined, it was found that ozone concentrations (daily maximum 8-hours data) in the summer-season will be increased by 2.7, 4.2, and 5.0 parts per billion (ppb) in the 2020s, 2050s, and 2080s, respectively, as compared to the 1990s, due to climate change alone (Hogrefe et al. 2004a, b). The influence of climate change on $PM_{2.5}$ aerosols and its constituent species have been investigated in an integrated Global Climate Modelling system-based simulation study. In the study it has been concluded that though $PM_{2.5}$ concentrations increased with climate change, the effects varied with the variation of their component species. Sulphates and primary aerosol increased markedly with rise in air temperature under different conditions (e.g. emission pattern), but organic and nitrated components (volatile one) decreased mainly because of their movement from the particulate to the gaseous phase (Hogrefe et al. 2006).

3 Recent Incidents Due to Climate Change and Their Effect

In a recent UN Environment report, it was mentioned that "*Climate action must happen now – the risks to our planet are greater than ever. Scientists warn of a climate cascade if global temperatures rise more than 2 °C above pre-industrial levels, leading to "hothouse" conditions and higher sea levels, making some areas on Earth uninhabitable*" (UN Environment 2018). This feature is not new. It is happening since last few decades. Frequent natural calamities are the persuasive examples of this phenomenon. Although some important pledges made under the Paris Agreement, global temperatures rise by up to 3.4 °C is unavoidable in this century, which will eventually change the current weather patterns. Many incidents like drought, forest fires, typhoons, sea level rise and coastal erosion, tsunami, desertification, more intense hurricanes, and frequent storms are the consequences of climate change. One has to remember that 'anthropogenic environmental pollution' too has contributed a lot in this climate change event. Table 1 summarised the few events that happened due to the *climate action* during the past few decades.

It is highly arguable whether these incidents are the *direct* consequences of climate change or not! Many secondary factors are also responsible and contributed substantially. *Ignorance* and *greed* of the people sometimes leads them to violate the natural/environmental rules and floods, forest fires, soil erosions, droughts etc. are the result of these unethical activities.

4 Eco-biological Effects of Climate Change

Ecological responses to recent climate change are well studied phenomena and extensively reviewed during the last few decades (Bellard et al. 2012). The Earth's climate has warmed by 0.5 °C over the last 100 years and it was reported that between 1880 and 2012, global mean annual temperatures were increased by ~0.85 °C and an additional 1–4 °C temperatures are likely to rise by 2100 (Stocker et al. 2013). This warm climate has already posed a great threat on our ecosystem and in future more worst scenarios are expected. Climate change in last few decades is affecting all levels of ecological organization. It changes population density (for all the species) in various geographical regions, species composition in communities and also the structure and function of ecosystems (Lafferty 2009; Walther 2010; Yang and Rudolf 2010). Considering the present climate trend, climate scientists are speculating that new ecosystems will emerge and existing ecosystems will be wiped out in future and this

Table 1 Climate change incidents during last few decades

Date/year	Incidents	Place	Effects	References
September 2018	Typhoon Mangkhut	Hongkong, Macau and Southern China	5.7 million people had been affected by the storm	Mullany et al. (2018). https://www.nytimes.com/2018/09/16/world/asia/typhoon-mangkhut-china.html
Early May 2018	Dust storm	Northern India; Rajasthan, Uttar Pradesh, Telangana, Uttarakhand, and Punjab	Over 120 people died and at least 300 people injured across several States	Aggarwal (2018). https://india.mongabay.com/2018/05/08/dust-storms-may-increase-in-india-due-to-climate-change/; Centre for Science and Environment, New Delhi, India
2016 and 2017	Mass coral bleaching	The Great Barrier Reef, Australia	Half of the living corals have died from bleaching	Moss and Morton (2018). https://www.cntraveler.com/gallery/10-places-to-visit-before-theyre-lost-to-climate-change
Since last 5 years	Consecutive flood	Venice, Italy	Flooding in Piazza San Marco and other parts of the low-lying city	
Since 1966	39 different glaciers suffered reduction in size (up to 85%)	Glacier National Park, Montana	Alteration of entire ecosystems will occur and little or no ice will be left by the end of the century	
No data available	The Dead Sea is shrinking at a rate of around four feet a year	The Dead Sea	Dead Sea could be completely dried up by 2050	

(continued)

Table 1 (continued)

Date/year	Incidents	Place	Effects	References
No data available	Extreme droughts	The Amazon	Tree species throughout the tropical jungle parched, frequent forest fires. If the situation lasts longer than 5–7 months then most of the tree species will die and the present situation is alarming	
Winter of 2013	Unusual warm temperatures brought rain to the peninsula which then froze and covered the pastured in a thick layer of ice	Yamal Peninsula, Russia	The reindeer, habitant of this place are not able to dig through the ice to find food, resulting in tens of thousands of the animals starving to death. In future they will suffer extinction	
NA	Sea level rise	The Maldives	People have forced migrated to new places and within a few years the country may also vanish entirely	
2017	Hurricane Irma; continual flooding	Key West, Florida	The sea level will rise 15 inches over the next 30-odd years	
NA	Inhospitable environment for grapevines	The Rhône Valley, France (the most vaunted winemaking regions in the world)	Production will be suffered and (predicting an 85% decrease) and winemakers will be forced to relocate to cooler places in Northern Europe	

(continued)

Table 1 (continued)

Date/year	Incidents	Place	Effects	References
In coming times	Sea level rise	Mumbai, India	In future decades major parts of the city will be in underwater and the city will suffer frequent flooding due to projected two-inch rise in water by 2050	
During last 50 years	Significant snowmelt	The Alps	One has to climb up to the 10,000-foot to see snow on the mountains	
2017–18	Forest fire	Napa Valley, California	Wine growing industry suffered disruption and economy affected significantly	
NA	Sea level rise	Rio de Janeiro, Brazil	It is projected that at current level of ascending temperatures, the sea level around Rio will rise up to 32 inches by the year 2100 and consequences will be destruction of famous beaches, airport, and even some inland neighbourhoods. Apart from that, flood, landslides, water shortages, and spreading of diseases will be occurred	
	Coastal erosion, sea ice retreat, and permafrost melt	Alaska	Intense landslides, wildfires. Severe destruction of forest was seen over the last ten years in Alaska than any other decade recorded, and by 2050 the number is expected to be doubled	

(continued)

Table 1 (continued)

Date/year	Incidents	Place	Effects	References
August 2005	Hurricane Katrina	Gulf Coast of Mississippi	Flooding of Lake Ponchartrain. 80% of New Orleans was left under water. More than 1800 lives were lost and hundreds are still missing. With more than $81 billion in damages, Katrina was the most expensive natural disaster in U.S. history	
September 2004	Hurricane Ivan	Gulf Shores, Alabama	121 people died and more than $19 billion damages was recorded	
2017	Tropical Storm Arlene Tropical Storm Bret Tropical Storm Cindy Tropical Storm Emily Hurricane Harvey Hurricane Irma Hurricane Jose Hurricane Maria	USA	Thousands of lives lost and billion of damages occurred; People were forced to migrate internally and ecology also suffered substantial lose	Irfan and Resnick (2018). https://www.vox.com/energy-and-environment/2017/12/28/16795490/natural-disasters-2017-hurricanes-wildfires-heat-climate-change-cost-deaths
2003–17	Forest fires in India increased by 46% in the last 16 years and by 125% in last two years	India	In 2017, the maximum number of forest fires were reported in Madhya Pradesh (4781) followed by Odisha (4416) and Chhattisgarh (4373)	Pandey (2018). https://www.downtoearth.org.in/news/forest-fires-in-india-increased-by-125-per-cent-in-last-two-years-60349

(continued)

Table 1 (continued)

Date/year	Incidents	Place	Effects	References
Last few years	Unusually large wildfires. It's occurring nearly five times more often since the 1970s and 80s	Alaska, Indonesia Canada, California, Spain, Chile and Portugal	Such fires are burning more than six times the land area as before, and lasting almost five times longer. Loss of lives and property; loss of biodiversity and ecology destruction as well as human and other animal migration	Brändlin (2017). https://www.dw.com/en/how-climate-change-is-increasing-forest-fires-around-the-world/a-19465490
Last few decades	Climate related changes	Papua New Guinea, Sierra Leone, Liberia and other parts of the world	Water sources become increasingly unreliable. Drinkable water gets contaminated due to increased flooding. In Papua New Guinea, the number of people without access to clean water close to home has increased to 4.8 million people, a 63% of the population	WaterAid. https://www.wateraid.org/us/where-we-work/papua-new-guinea
Last few decades	Coral reefs and marine eco system destruction	Hawaii	Coral reefs and other marine ecosystems damaged. As average precipitation decreased in the last century, freshwater availability decreased in appreciable amount and affecting delicate land-based ecosystems, often harming native species. In the last 50 years, due to sea level rise along Hawaii's shores, coastal communities are in suffering end	US-EPA (2016). What Climate Change Means for Hawaii, 2016

shift in biomes will be irreversible. Some species may be eliminated entirely, cold-adapted systems (e.g. arctic and alpine communities) may turn into warming, and low-elevated islands may disappear due to sea level rise. It will be a great challenge for the existing species for their survival in the new ecosystem because their migration or shift will be drawn from the existing condition and ultimately "*fittest*" will "*survive*". Climate change has occurred many times throughout the Earth's history, but the increasing anthropogenic activities during the last few decades are amplifying the ecological impacts of the current climate alterations.

4.1 Effect and Consequences of Climate Change on Ecosystem and on Biodiversity

The multivariate factors of climate change are supposed to have an effect on all the levels of biodiversity, starting from organism to biome levels (Parmesan 2006). Ecosystem functioning and resilience are affected due to decrease in genetic diversity as climate change is forcing the population for directional selection and rapid migration (Botkin et al. 2007; Meyers and Bull 2002). Disappearance of around 6300 species among the 9650 interspecific systems, including pollinators and parasites, suggested that along with individual species extinction, associated species extinction is also a major concern (Koh et al. 2004). Due to gradual climate change phenological shifts are happening in flowering plants and insect pollinators. Plant and pollinator populations do not fit well with each other which may lead to the destruction of structure of plant-pollinator networks, resulting in extinctions of both the species (Kiers et al. 2010; Rafferty and Ives 2010). At a higher level of biodiversity, vegetation communities are influenced by climate related changes and shifting of 5–20% of Earth's terrestrial ecosystems, in particular cool conifer forests, tundra, scrubland, savannahs, and boreal forest has been anticipated in the Millennium Ecosystem Assessment (Sala et al. 2005). Extensive studies have been done on this subject during the last few decades (Peters and Lovejoy 1994; Lovejoy and Hannah 2006; Willis and Bhagwat 2009) and were summarized in various reports (Gitay et al. 2002; Steffen et al. 2010; Karl et al. 2009; Millennium Ecosystem Assessment 2005a, b). It is predicted that in distant future a major part of the Amazonian rainforest could be taken over by tropical savannahs (Lapola et al. 2009); at higher altitudes and latitudes, alpine and boreal forests might expand towards north by shifting their tree lines upwards by outlaying low stature tundra and alpine communities (Alo and Wang 2008). Global temperature rise will warm up the oceans which will increase the acid level and consequently tropical coral reefs will be degraded soon (Hoegh-Guldberg et al. 2007).

At present the most concerning issue is extinction because "*Life once lost-lost forever*". Climate change affects species individually (Root et al. 2003) and as a community as well. While calculating the extinction risk, 'suitable habitat' and 'weak habitat specificity' are the main issues to be considered. But sometimes species enters into the "extinction vortex" well before they lose their habitat (Jetz et al. 2007; Malcolm et al. 2006; Willis and Bhagwat 2009). The 'International Union for Conservation of Nature (IUCN) Red List of the conservation status of plant and animal species' (Baillie et al. 2004) includes 90 highly vulnerable biological traits based on their habitat specificity, limited environmental tolerance, dependence on specific environmental activators, dependence on inter-specific interactions or restricted ability to disperse to or colonize a new range (Foden et al. 2008). Many models have been developed to estimate this species loss (both local and non-local). It is predicted that due to intermediate climate warming 15–37% of species will suffer extinction by 2050 (Thomas et al. 2004). Among all the vulnerable species, particularly birds are very sensitive to climate change. It was found that by 2100 approximately 0.3% of the world's 8750 land bird species (Jetz et al. 2007) and up to 30% of the Western Hemisphere's 8400 land bird species could go extinct (Sekercioglu et al. 2008) because of changing climate. After few studies done on vulnerability of 25 major biodiversity hotspots, it was predicted that, in long run 56,000 endemic plant species and 3700 endemic vertebrate species will be lost (Malcolm et al. 2006). Based on the data analysed from 9856 birds, 6222 amphibians and 799 coral reefs, IUCN has estimated that about 35% of the world's birds, 52% of amphibians and 71% of warm-water reef-building corals are going to face negative effect of climate change (Foden et al. 2008). A detailed study was conducted on Amazon basin, central Indo-west Pacific (Coral Triangle) for birds, amphibians and corals (16,857 species) and depicted that 608–851 bird species (6–9%), 670–933 amphibian (11–15%), and 47–73 coral species (6–9%) were vulnerable due to climate change and already threatened with extinction on the IUCN Red List (Foden et al. 2013). While projecting the species loss, it has been found that chances of local extinctions are significantly higher than that of global extinctions. *Global multi-taxon meta-analysis* data generated from recorded ecological responses projected that *mean observed extinction risk* (by 2100) is much higher than the *mean predicted extinction risk*; e.g. 12.6% in plants (vs. 4% predicted), 9.4% in invertebrates (vs. 7.2% predicted) and 17.7% in vertebrates (vs. 12.4% predicted). Overall, these systematic biodiversity losses are really alarming for our planet's health (Maclean and Wilson 2011). It is important to mention here that only climate change is not the reason for species loss but other natural processes (e.g. changes in land use and cover, introduction of invasive species, species interactions within ecological networks etc.) are also contributing to this.

Conservation is also facing some unexpected challenges due to global temperature alteration. It was found that in warmer conditions, painted turtle (*Chrysemys picta*) eggs raised to produce female offspring, whereas under cooler conditions males were predominant (Janzen 1994). This evidence showed that painted turtles are going to suffer local extinctions in the near future. Climate warming also pose significant effects on the population and reproductive biology of different organisms. Due to warmer winter in southern Norway, population dynamics of dippers (*Cinclus cinclus*) had changed and increase in population size was noticed (Saether et al. 2000). In Germany, Pied Flycatchers (*Ficedula hypoleuca*) and Reed Warblers (*Acrocephalus scirpaceus*) showed positive effect in their reproduction which was supposed to be associated with climate warming of 1.38 °C in spring time (Winkel and Hudde 1997;

Bergmann 1999). In contrast, 90% decline of the abundance of Sooty Shearwaters (*Puffinus griseus*) in western North America between 1987 and 1994 (Veit et al. 1996, 1997) was reported and the main cause was rapid warming of the California current. Changes in ocean temperature which give rise to the event like *El Niño* also have widespread ecological effects and could change the population sizes of intertidal invertebrates along with coast lines (Barry et al. 1995). In the Antarctic, due to gradual increase in temperature ice cover is reducing and animals such as penguins are the worst affected. Precipitation is also a determining factor for conservation where variation of precipitation level could change the natural systems; e.g., moisture sensitive ponderosa pine forest (*Pinus ponderosa*) and piñon-juniper woodland (*Pinus edulis* and *Juniperus monosperma*) in New Mexico response abruptly in their distributions pattern (Allen and Breshears 1998). Negative effects have also been evident when precipitation occur in the form of snow; e.g. browsing and grazing animals like muskoxen (*Ovibos moschatus*) and deer have suffered significantly when they search for food and try to save themselves from predators (Forchhammer and Boertmann 1993; Post and Stenseth 1999). It should be remembered that the '*proportion of species extinction is a power function of the expected global warming*' (Hansen et al. 2010). Therefore, any attempt to minimize global warming could result in non-linear effects in the protection of species from extinction (Hansen et al. 2010). Therefore, our focus should have been on the *act* to reduce global warming instead of focussing on its effect on biodiversity. In parallel, we should plan to reduce other *global change drivers* so that overall resilience of biodiversity against the climate change could have been increased significantly (Hughes et al. 2003).

Climatic changes are not only responsible for negative effect on ecosystem but also have some positive effects on biodiversity. Accelerated growth has been noticed in many plant species due to more pleasant temperatures and due to increased CO_2 level. Many threatened species could have survived because of milder winters and increased precipitation may also be beneficial for several plant species and plant communities.

5 Climate Migration and Socio-economic Effect

Extinction and shifting of *non-Homo sapiens* are not the only consequences of climate change; human migration is also a major issue in this respect. During the last few decades increasing climate related incidences have led people to migrate to safer places from less habitable ones and allowing new economic activities such as agriculture, industry related job opportunity or tourism. But it is difficult to estimate how many people might have moved partially in response to different natural calamities such as drought, forest fires, or desertification. It is obvious that patterns of migration and displacement are highly influenced by changing climate and therefore policy-makers are trying to understand its mechanism which may help them to frame the policies to tackle it. The vulnerability, capacity and impacts of human migration should not be addressed only in view of disaster risk management efforts or humanitarian assistance, but should also be dealt with considering sustainable development processes. Human migration is not a new phenomenon as this has happened throughout history; but anthropogenic activities which are mainly responsible for recent climate change complicates this scenario. Flooding, sea-level rise and abnormally high temperatures around the globe are the results of increasing drought, uneven rainfall and global temperature rise (Blunden and Arndt 2017). Due to the abrupt change in climate in many regions of the world, climate-related hazards are very frequent. The frequency, intensity, duration, and timing of these slow and sudden hazards may vary (IPCC 2012, 2014) but its overall impact is destruction of the ecosystems. One should not forget that all the living beings are highly dependent on the ecosystem with respect to water, food, energy and other important services (Cozzetto et al. 2013).

In 2016, sudden-onset climate-related hazards like typhoons and floods have forced to displace over 24 million people which were 32 times more than other geophysical hazards (IDMC 2017). In 2016, storms and floods together were responsible for ten largest disaster displacements (Table 2). During 2008 and 2016, 99% of internal displacement happened because of sudden-onset events and an average of 21 million people were migrating annually. Apart from these sudden incidences, slow-onset climate-related hazards are also responsible for continuous migration of people either temporarily or permanently (Bremner and Hunter 2014). This includes drought, desertification, salinization, ocean acidification, glacial retreat and sea-level rise and changing trends in seasons. A few case studies were documented in this regard (Foresight 2011; Laczko and Piguet 2014; Dina et al. 2017). These hazardous effects generally last longer and have long term implications.

Many governmental and non-governmental organizations have predicted that a billion people may be displaced by 2050 as a result of environmental causes, and

Table 2 The ten largest displacement events of 2016 due to climate issues

Country/place	Number of people displaced	Reasons
China	1,990,000	Yangtze River floods
	782,000	Typhoon Haima
	658,306	Typhoon Megi
	567,000	Typhoon Meranti
Cuba	1,079,214	Hurricane Matthew
India	1,670,000	Bihar floods
Indonesia	948,098	Rainy season floods and landslides
Philippines	2,592,251	Typhoon Nock-Ten
	2,376,723	Typhoon Haima
USA	875,000	Hurricane Matthew

Source The Internal Displacement Monitoring Centre (IDMC) database (2017) climate change will be one of the major contributors (Stern 2006; Christian 2007). The Environmental Justice Foundation (EJF 2017) in their recent report suggested that hundreds of millions of people will be 'forced migrated' by 2100 due to sea-level rise. United Nations (UN) in their migration report mentioned that as of 2015, approximately 244 million people migrated *from* their own country, and another 740 million were displaced *within* their country (UNDESA 2016). The Global Knowledge Partnership on Migration and Development (KNOMAD) project estimated that more than 700 million people a year may likely get internally displaced but this data was not verified by any true scale (KNOMAD 2017; Bell and Edwards 2013). Displacement of 40.3 million people in the year 2016 was reported by the Internal Displacement Monitoring Centre (IDMC 2017) and the main cause was both conflict and sudden-onset hazards. In 2016, the most number of internal displacements took place in Democratic Republic of Congo, Syria, Iraq, Afghanistan and Nigeria. Internal displacement mainly occurred in those places where vulnerability is high and in situ management is difficult. Table 3 showed the list of countries which suffered climate related displacement in the year 2016. Many countries in the list are still vulnerable to future climate change and going to lose their human population. In 2017, internal displacements of 18.8 million people in 135 nations took place due to sudden-onset disasters and the most affected regions are South and East Asia (in particular, China, the Philippines), the Caribbean (mainly Cuba), and the Pacific. Extreme weather events, like hurricanes Harvey, Irma and Maria in the Atlantic and the Caribbean, and a series of typhoons in South and East Asia and Pacific were responsible for this *climate migration* (IDMC 2018).

Table 3 List of countries with climate related displacement data for the year 2016

Country	Region	Climate related displacement in 2016	Vulnerability to climate change[a]
Philippines	South-East Asia	5,930,000	50.8
India	South Asia	2,400,000	46.4
Indonesia	South Asia	1,246,000	50.9
Myanmar	South-East Asia	509,000	37.6
Ethiopia	East Africa	347,000	40
Democratic Republic of Congo	Central Africa	130,000	32.5
Nigeria	West Africa	78,000	40.1
Yemen	Middle East	45,000	32.2
Colombia	South America	31,000	56.2
Afghanistan	Central Asia	7400	32.4

[a]The ND-GAIN Index, which ranges from 0 to 100, measures a country's vulnerability to climate change in combination with its readiness to improve resilience. The lower the number, the more vulnerable the country is

The table was extracted from UNDP report 2017 (Stapleton et al. 2017)

Source Data from IDMC Database (2017), ND-GAIN (2017) and Chen et al. (2015)

'Climate migration' is a complicated matter as climate-related hazards are not the only cause for migration but underlying factors like socio-economic, cultural, political, personal, lack of support from state and other environmental processes are also responsible for human displacement (Laczko and Aghazarm 2009; Foresight 2011). In general, people do not want to move as moving is not only costly affair but also lead to detachment of people from social networking and their livelihoods (Cubie 2017; Adger et al. 2007). In contrary to loss of habitat, migrations sometimes (or many times!!) pose positive effect on the economy of a particular region. It can be helpful to reduce poverty by generating economic opportunities in some specific area. Urbanization is a good example related to the opportunities and challenges of human migration under these circumstances.

One of the biggest issues related to climate migration is that if proper adaptation planning has not been followed then the vulnerable group can end up in other hazard-prone locations. In contrast, planned relocation can reduce damage and bring benefits, can help to manage future climate change risks, can save lives and livelihoods and even generate better employment possibilities. Best example of planned migration is in the case of Dominican Republic, Papua New Guinea and Vietnam. If the climate change hazard is robust then it is difficult to arrange 'planned migration' but countries like USA, China whose economy is much healthy are able to plan properly for guided migration. Improved weather forecast system has contributed a lot in this purpose.

Unfortunately, very few or no data has been reported by any of the leading environmental organizations related to the migration of animal populations. Due to climate related hazard not only human population suffered but also huge population of animals and other small creatures are in the verge of extinction because of their *native habitat loss*. Still people do not bother about this loss and *Anthropocentrism* is the main cause for this ignorance!

6 Conclusion

In general, it has been found that people are less bothered about climate change and this issue is in their lowest priority list. They are reluctant to change their behaviour, even if they are aware of this problem. Most of us do not feel personally responsible for climate change as we think climate change is a *global effect*. Depending on basic demographic (gender, age, education) and economic characteristics (income), people's reaction is varied related to environmental issues. Interestingly those who are more educated (or informed) are less concerned about it, but, rather more interested to support pro-environmental social policies. It's a lot about media reporting and how the media (including social media) report the issues, people reacted according to that; but unfortunately the effects faded down with time. Many environmental organizations (both governmental and non-governmental) has taken some bold and positive steps to lower down the effect of climate change and continuously fighting with people (or industries!) who are responsible for global climate alteration. Educating people and implementation of strong laws should be imposed to fight against climate change effect. Now it's a high time to *react* otherwise it will be too late to tackle this issue because *Anthropocentrism* will remain forever.

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Conflict of interest Authors declare no conflict of interests.

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Socio-economic and Eco-biological Dimensions in Resource Use and Conservation: Epilogue

Niranjan Roy, Shubhadeep Roychoudhury, Sunil Nautiyal, Sunil K. Agarwal and Sangeeta Baksi

Abstract Use of natural resources largely determines the standard of living that human societies enjoy. Steady increase in worldwide use of biotic and abiotic resources (such as water, air, soil, biodiversity, land as habitat etc.) for a range of societal purposes (such as wind power, solar power, tidal flows etc.) have been linked with rapid population growth. Current as well as potential future flows of income are often associated with the economic significance of natural resources. In the poorest regions of the world, such resources form the basis for the wealth generation and hence are also considered as the basis of livelihoods. In such poor rural communities, a reduction in stocks of natural capital and flows of ecosystem services may disproportionately harm their wellbeing. Although a number of reports are available at regional, national and global levels that deal with climate smart livelihoods and socio-ecological development, for a mega-diverse country like India the studies which mostly cover the national status are not going to propose the sound approaches for the people and landscape of its varied agro-climatic regions. The purpose of this volume is to provide findings of different and differing studies done in diverse agro-climatic zones to the stakeholders in a compiled and comprehensive manner to enable

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them to inject the research findings in reframing or reorientating the policies (if necessary) that are required as strategies for sustainable socio-ecological development, natural resource management and biodiversity conservation.

Keywords Biodiversity and agro-diversity management · Livelihood issues · Conservation perspective · Human-wildlife conflict · Climate change adaptation · Sustainable natural resource utilization · Environmental protection

Use of natural resources largely determines the standard of living that human societies enjoy. Steady increase in worldwide use of biotic and abiotic resources (such as water, air, soil, biodiversity, land as habitat etc.) for a range of societal purposes (such as wind power, solar power, tidal flows etc.) are linked with rapid population growth (TU 2014a). Fundamental life support is provided by natural resources in the form of both consumptive and public-good services (Meinzen-Dick 2017). Current as well as potential future flows of income are often associated with the economic significance of natural resources (OECD 2011). Their sustainable use is not only a question of sustainable economic development but also of protection of the environment. In the poorest regions of the world, such resources form the basis for wealth generation and hence often form the basis of livelihoods. In poor rural communities, a reduction in stocks of natural capital and flows of ecosystem services may disproportionately harm societal wellbeing (UNEP 2015). In fact, functioning ecosystems provide a range of services from waste absorption, water and nutrient cycling, seed dispersal and pollination, controlling agricultural pests and providing food to habitat for species. These allow the ecosystem goods (called natural resources) to be produced and maintained. The provision of ecosystem services is necessitated by timber, fish and wildlife, clean water and air, and agricultural production etc. (OECD 2011). The chapters by Nautiyal et al. (Chapter "Medicinal Plant Biodiversity in India: Harnessing Opportunities for Promoting Livelihood and Food Security") and Chauhan et al. (Chapter "Biology, Uses and Conservation of *Trillium govanianum*") sheds light on how rural communities in India harness the diversity of medicinal plants for their livelihood and food security and authors have proposed an overview of the biology, uses and conservation approaches that can be followed for the conservation and sustainable utilization of biodiversity in Indian Himalayas. In another chapter (Chapter "Transitional Peri-urban Landscape and Use of Natural Resource for Livelihoods"), Goswami and Nautiyal focused on the use of natural resource for livelihoods in transitional peri-urban landscape. In their chapter (Chapter "Livelihood Strategies and Agricultural Practices in Khonoma Village of Nagaland: Observation from a Field Visit"), Roy et al. analyzed the livelihood strategies of indigenous communities in terms of improved agricultural practices as an alternative to shifting cultivation transforming towards terrace cultivation by using Aldar trees in Nagaland state of north eastern India.

However, higher growth may not necessarily lead to sustainable development unless it is accompanied by environmental protection. An efficient demand management policy by emphasizing conservation and prudent use of environment can also increase the supply of reserves (Roy 1998). In the chapter by Das et al. (Chapter "Wildlife Conservation Perspective of Fringe Villagers and Their Socio-economic Dependency: A Case Study from Borail Wildlife Sanctuary, Assam, India") authors have analyzed the wildlife conservation perspective of local communities and their socio-economic dependency on natural resources in conservation areas of north eastern India. Based on the findings of the dominance of utilitarian value among the local communities and their social and economic dependency on the sanctuary, particularly for collecting firewood, constructing huts (*kutcha* houses), shifting cultivation of beetle vine (*pan jhum*) they advocated for strengthening the sanctuary-community relationship. This may help in persuading the rural population to give up unsustainable forms of livelihood in order to protect the sanctuary which might hold the key to participatory wildlife and biodiversity conservation programmes. Dutta and Hazarika (Chapter "Assessment of Different Aspects of Elephant Depredation at a Rural Society-Protected Area Interface in Northeast India Based on Public Estimation") focused on human–elephant conflict in a reserve forest of north eastern India thereby revealing severe financial consequences on the rural population due to attacks by elephants which resulted in widespread agricultural loss, property damage and human injury. Researchers often relate the social consequences of resource use to social issues ranging from equitable distribution of raw materials, ready access to clean water, and global food security, among others (TU 2014a).

The nation states strive to improve economic welfare largely at the costs of nature and future generations (UNEP 2015). Resource conservation aims at securing sufficient natural resources for future generations, and minimizing the impact of their use on environment (TU 2014b). With only 2.4% of the world's land area, India is home to 16% of the world human population. India contributes greatly to the global biodiversity with about 8% of total number of species (Khoshoo 1996). It is a mega-diverse country in terms of both people and biodiversity. India ranks 10th among the countries with the largest forest cover in spite of highly variable forest distribution across its various regions (FAO 2010). In the chapter (Chapter "Biodiversity and Conservation: India's Panoramic View"), Kapoor and Usha presented a panoramic overview of India's biodiversity and its conservation issues. In a case study from the Eastern Ghats region of India, Gandhi and Sundarapandian (Chapter "Plant Diversity and Distribution Pattern in Tropical Dry Deciduous Forest of Eastern Ghats, India") analyzed vegetation of a tropical dry deciduous forest and further observed significant spatial variations in species richness and density among the plots having anthropogenic perturbation, and edaphic characteristics. The challenge for biologists in conservation of wildlife and biodiversity for maintaining ecological balance has been widely recognized. In their chapter, Purkayastha et al. (Chapter "A Preliminary Checklist of Herpetofauna Occurring in Rowa Wildlife Sanctuary, Tripura, India") reported illegal turtle trade by local communities while preparing a checklist of herpetofaunal diversity in Rowa Wildlife Sanctuary in Tripura state of north east India. In another chapter (Chapter "Herpetofaunal Diversity and Conservation Status in Amchang Wildlife Sanctuary of Assam, India"), Purkayastha et al. not only prepared an inventory of herpetofaunal diversity in Assam's Amchang Wildlife Sanctuary but also identified the perceived threats and conservation concerns based on The International Union for Conservation of Nature's Red List of Threatened Species as well as India's Wildlife (Protection) Act, 1972.

Moreover, the huge variety as well as numbers of livestock population puts enormous pressure on India's shrinking natural resources. Land degradation has become a major threat to the food security with as high as 37% of geographical land area being affected (ICAR 2010).

Conservation inevitably involves social benefits and social costs both (Springer, 2009 http://www.conservationandsociety.org/article.asp?issn=0972-4923;year=2009;volume=7;issue=1;spage=26;epage=29;aulast=Springer). In the chapter (Chapter "Impact of Weather Shock on Food Insecurity: A Study on India") on the impact of weather shock on food insecurity involving determinants across space and different social and religious groups, Mandal and Sarma identified rainfall deficiency, size of households and dependency ratio as probable factors inducing food insecurity in India. The chapter by Kumar and Saikia (Chapter "Forest Resources of Jharkhand, Eastern India: Socio-economic and Bio-ecological Perspectives") dealt with the socio-economic and eco-biological perspectives of forest resources and the concerns associated with their over-exploitation in an eastern Indian state of Jharkhand. Dhyani and Dhyani (Chapter "Local Socio-economic Dynamics Shaping Forest Ecosystems in Central Himalayas") observed that degradation of forest eco-systems have failed to generate sufficient goods and services to support a good quality of life for marginal communities living in Central Himalayas who are directly dependent on these resources for their livelihood.

On one hand, natural resources act as indispensable production factors for agriculture and forestry, while on the other their indiscriminate use serve as emission sinks and generate environmental pollution across the supply chain. Unsustainable use of the resources for short term economic benefit may provoke irreversible ecological and/or social change(s) (TU 2014a). Due to environmental variability and climate change resources are compromised and already shrinking, which may further risk their mismanagement (Stephenson et al. 2010). In Chapter "Carbon Sequestration Potential of Trees in Kuvempu University Campus Forest Area, Western Ghats, Karnataka", Narayana et al. highlighted the carbon sequestration potential of trees in Kuvempu University campus forest area in Western Ghats of Karnataka state in India. In his chapter (Chapter "Exploring Synergistic Inter Linkages Among Three Ecological Issues in the Aquatic Environment"), Himangshu Dutta examined the synergistic impact of climate change on aquatic environment while emphasizing the linkages of climate change with eutrophication and species invasion. Using statistical tools, the study further observed that aquatic ecosystems can effectively be conserved against the harmful effects of global change.

Research is urgently needed at micro level to come up with adequate strategies for sustainable conservation of key resources and biodiversity without depleting the natural resource base. In this context, agro-biodiversity has come up as a major thrust area in minimizing biodiversity loss and habitat destruction. The traditional approach of agroforestry practiced by the indigenous communities in sensitive and vulnerable landscapes of India's north east as a potential alternative to the unsustainable use of bioresources in terms of indiscriminate slash and burn agriculture (locally known as *jhum* cultivation) has been discussed in detail by Deb in his chapter (Chapter "Traditional Agroforestry Systems of Northeast India"). In their chapter, Das and Das (Chapter "Agrobiodiversity in Northeast India: A Review of the Prospects of Agrobiodiversity Management in the Traditional Rice Fields and Homegardens of the Region") lucidly presented the prospects of agrobiodiversity management in the traditional rice fields and home gardens of north eastern region of India.

The chapters by Kumar et al. (Chapter "Climate Change Impacts and Implications: An Indian Perspective"); Chatterjee and Tandon (Chapter "Climate Change Impact on Eco-biology and Socio-economy—A Concise Discussion") thoroughly examined the impacts of climate change on India's agriculture, forestry, ecosystems, socio-economy and biological diversity and other allied sectors but also highlight the role of research in coming up with strategies and approaches for adaptation and mitigating of such changes. Dar et al. (Chapter "Role of Major Forest Biomes in Climate Change Mitigation: An Eco-Biological Perspective") chapter leads to the development of a detailed perspective of three major forest biomes namely tropical, temperate and boreal, and elaborates their unique features which vary in their response to climate change as well as mitigation potential and response. It helps to understand different types of impacts of climate change and the crucial roles played by major forest biomes in climate change mitigation, as well as their ecological services in order to formulate better strategies for forest management. Employing a suitable statistical model based on a given set of climate data on independent and dependent variables is of paramount importance for proper understanding of the socio-economic (agriculture, industry, tourism, transport, consumption, lifestyle), eco-biological (evolution of flora and fauna, living condition of populations, territory) and cultural (values and perceptions of trends on conservation and sustainability) dimensions of climate change in order to devise climate adaptation and mitigation strategies by sustainable use of natural resources and conservation for future generations. The importance of emerging technology models to address the emerging challenges of inclusive growth at India's grassroots level has been emphasized by Agarwal in his chapter (Chapter "Emerging Technology Intervention Model of Core Support for Inclusive Rural Growth: Social-Economic-Ecological Interface Building Through Innovative Scalable Solutions & Effective Delivery Mechanism"), wherein the author recognized the necessity for integrating government policy level interventions for science and technology networking with non-governmental organizations for maintaining a vibrant ecosystem in order to bring about accelerated visible transformation India's in rural areas. The chapter by Shalabh and Dhar (Chapter "Statistical Modelling and Variable Selection in Climate Science") addressed the issue of proper analysis of climate data using multiple linear regression modelling and LASSO techniques particularly for subset selections of important explanatory variables, which may prove significant for safeguarding rural livelihood and ensuring sustainable development.

Scientific study and assessment of adaptation as well as mitigation approaches of rural communities affected by climatic variations assumes great significance in agricultural landscapes. In this context, the chapter by Lalitha (Chapter "Climate Change and Adaptation Strategies in the Gir Kesar Mango Region of Gujarat") put forth a case study of climate change adaptation in the Gir Kesar Mango Region of Gujarat wherein inadequate rain threatens the water table to go down thereby increasing the salinity level that would potentially affect not only the cropping pattern but also the quality of product. In the following chapter, Abirami and Kumar (Chapter "Spatial Shift in Chickpeas in India: Role of Climatic Factors") used the example of chickpea to explain the role of climatic factors in spatial shift in cropping pattern in India.

The major challenges of twenty-first century is to address the critical issues like mitigation of climate change effect, sustainable natural resource utilization for sustainable socio-ecological and economic development of people and biodiversity conservation. There is an urgent need to identify the key mechanisms underpinning climate change impacts on the complex socio-ecological systems in India. India is home to two important global biodiversity hotspots namely the Himalaya and the Western Ghats. These hotspots are important not only for biodiversity but also for about 300 million people living over there and many more residing in adjacent plains. The livelihood of the people in biodiversity hotspots centered on the land use and the resource availability and found to be highly climate sensitive. For climate smart livelihood and sustainable socio-ecological development, sensible use of available land, water, and forest resource in biodiversity rich areas is of paramount importance. In this perspective very limited work is available in the biodiversity hotspots.

In a developing country like India, where still more than two lakhs villages are forest villages the development cannot be compensated with present day concept of total conservation of natural resources. Therefore, evaluation of the socio-ecological systems and assessment of ecosystem services would enable the stakeholders to propose the win-win solutions for development and conservation. Variety of factors are responsible for influencing the dynamic relations between humans and ecosystems for the sustenance in natural resource rich areas. IPCC latest report has indicated that the climate change has become one of the major drivers that have impacted the socio-ecological systems of bio-diversity rich areas. Thus there is a need for developing scientifically proven strategies for resource conservation, their sustainable utilization in order to provide long term socio-ecological sustainability to the biodiversity hotspots. To understand this, in-depth study in selected study regions of biodiversity hotspots will be undertaken to understand the resource availability, resource requirement, and resource utilization for sustainable socio-ecological development in the hotspots. The temporal change pattern will be assessed for measuring the sustainable flow of resources in the landscapes.

Lot of studies/reports are available at regional, national and global level that deals with climate smart livelihoods and socio-ecological development. However, for a country like India where diversity in nature, people, culture, land use, resources, practices, languages, societies, development and the many different perspectives exist, the studies which mostly cover the national status are not going to propose the sound approaches for the people and landscape of various agro-climatic regions of the country. Unfortunately, there is no such dynamic *orchestrated model* for various agro-climatic regions in India as a ready reference that could have been able to help develop the understanding of impact of various factors (for example climate change, population growth, unsustainable resource utilization, socio-economic and socio-cultural changes and many others) on landscape—i.e. biodiversity, socio-economic, health, natural resource management, landscape development and sustainable development of the socio-ecological systems and the adaptation strategies by the people. Therefore, this volume has made an attempt to include the studies done in various agro-ecological regions of India in order to understand the dynamic process of social and ecological interactions in natural resource use and conservation from species to community level. The purpose of this volume is to provide findings of various studies done in diverse agro-climatic regions to the stakeholders in compiled and comprehensive manner to enable them to inject the research findings in reframing or reorientation of the policies (if necessary) that are required as strategies for sustainable socio-ecological development and sustainable natural resource management and biodiversity conservation.

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