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Sustainable Forestry Under Changing Climate

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Abstract

Climatic perturbation is the major event in the present era that has put the survivality of human civilization under severe threat. Forests are natural boon for us to combat the mega event of climate change. Apart from mitigating climate change, the forests are providing livelihood for community stakeholders, meet up energy demand, provide fodder and fuel and produce various non-timber forest products (NTFPs). Consideration of different multidimensional role of forest is essential for survivality of human civilization. As per the Intergovernmental Panel on Climate Change (IPCC), mitigating climate change through forest appears to be up to 14.0% at various sectors. On the other hand, forests are supporting livelihood security for more than 300 million people of India and meet the energy demand of rural India up to 40.0%, and to provide support for domesticated animals up to one-third. But the existence of forest is under threat due to the rapid growth of human civilization, resource dependency and unsustainable use of forest resources. Therefore, climate change is showing its impact over forests at various levels such as in the form of productive traits, C (carbon) dynamics, vegetation shift and depletion of soil resources. To combat such problems, sustainable forest management (SFM) is a suitable answer as it addresses multidimensional way by reducing resource dependency on one hand and promoting livelihood option for forest dwellers on the other hand. This chapter deals with SFM practices under the changing scenario of climate change. SFM promotes increase in forest cover which further helps to combat and adapt to climate change events. In this way SFM becomes an integrated approach of sustainable management and conservation of natural resources.

Keywords

Biodiversity · Climate change · C dynamics · SFM · Soil resource

Abbreviations

AFOLU	Agriculture forestry and other land use
C	Carbon
CO_2	Carbon dioxide
FAO	Food and Agriculture Organization
FOLU	Forestry and other land use
GHGs	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
N	Nitrogen
NFP	National Forest Policy
NTFPs	Non-timber forest products
OC	Organic carbon
OM	Organic matter
REDD	Reducing emissions from deforestation and forest degradation
SFM	Sustainable forest management

1 Introduction

Forest resource nowadays has become the most scarce resource due to its higher amount of anthropogenic pressure. Mostly the resource dependency of the forest-dwelling community as well as people living in the forest fringes has promoted a higher level of forestland degradation in the recent decades. Forests have multifaceted benefits for the entire human civilization such as economic benefits, ecological benefits, environmental benefits and sociocultural benefits (FAO 2006; Jhariya 2017; Jhariya and Yadav 2018). As a consequence of that, the urgent need for forest conservation has come into the forefront. Forest conservation not only benefits the forest-dwelling communities, but also on a broader scale, it promotes conservation of biodiversity (Jhariya and Raj 2014).

Now on a global scale, forest regulates climate and hydrological cycle and also mediates proper cycling of nutrients. Therefore, forests act as global carbon (C) sink as well as sink for other greenhouse gases (GHGs). Forest has holistic approach in terms of maintaining GHG budget through C dynamics in vegetation and soil, providing biomass as an alternative for fossil fuel and also as raw materials that can produce higher energy for industrial purpose. Forest tends to actively participate in the hydrological process of the nature by promoting rainfall, interception of precipitation as well as sometimes promoting water conservation. Forests often serve as an effective pollutant remover from the atmosphere through moistening and filtering activity. Forest has got some protective action in terms of erosion prevention and desertification (Heal 2000).

As forest is a key resource from an economic perspective, maintaining sustainability is the need of the hour. This has generated the origin of sustainable forest management (SFM). It harbours the three dimensions of sustainability, i.e. economic dimension through sustainable harvesting, ecological dimension through maintaining the integrity of forest ecosystem and social dimension through socio-economic upliftment of rural livelihood. The world is moving towards a low C economy as was mentioned in the agenda of United Nations 2030 vision. This would promote effective management towards sustainable utilization of resources present over the earth's surface. Climatic perturbation is the biggest threat for mankind nowadays. From combating perspective, SFM would help the society to build a sustainable world.

Climate and forest are intricately related with each other. This fact is further proved by the presence of different types of forest on the global scale depending upon the climatic nature. Again climatic changes are too severe for the well-being of vegetation for a particular area (Raj et al. 2018a; Jhariya et al. 2018; Meena et al. 2016). Therefore, proper adaptation needs to be incorporated in the system of SFM. SFM can be achieved through sustainable utilization of resource adopting climatic mitigatory measures under climatic perturbation in the upcoming century.

Climate change and forest together are such a complex issue that multidimensional problems reorient between the two. For instance, climate change alters forest configuration, and forestland degradation produces up to 20% carbon dioxide (CO_2) emission globally. On the other hand, forests provide opportunities by acting as GHG sink for mitigating climate change. Perturbations through climate change on forest ecosystem lead to biodiversity loss, loss of biomass and reduced capacity of forest regeneration (Raj et al. 2018a).

This chapter deals with various aspects about the interrelationship of climate change with forest, impact of climate change over forest and SFM and its consequences.

2 Interrelationship Between Forest and Climate Change

Globally climate change has been found to be intricately related with forest ecosystem producing variable responses. The major impact that climate change imposes includes alteration in the growth as well as the C cycle. During the past century, scientific exploration has revealed that climate change can be indicated through alteration of composition of species and changing pattern of growth in diverse type of forest ecosystems. Under changing climate, forest management is the biggest challenge as it may magnify the negative impacts on forest ecosystem. For example, climatic elements such as precipitation and temperature regime alteration may prove to be critical for forest development. The major influence played by forest is in the form of biomass production and ecosystem resilience, and storage of CO_2 may be hindered unless climatic considerations are considered in case of tree growth parameters (Jhariya 2014; D'Aprile et al. 2015; Berndes et al. 2016; Dhakal et al. 2016). The opposite side of the coin includes creating favourable climate for maximum growth leading to higher wood production and more storage of C (Fig. 1).

Globally it was found that extreme climatic event imposes significant influence over the distribution pattern of vegetation. As climate and forests are intricately related with each other, forest imposes its influence over climate through changes in the land surface reflectivity, roughness and conductivity. Under climate change scenario, water stress condition imposes a significant influence over the species composition of forests (Table 1). For example, the forest community is dominated by shrubs/grassland instead of trees due to higher vulnerability due to root length and fire hazards (Jhariya 2017). It has been reported that temperature decrease makes taller trees much vulnerable in comparison to ground vegetation. Under extreme cold conditions such as polar region and alpine ecosystem, mosses and lichens reflect sparse presence (Whittaker 1975).

In the Asian subcontinent, climate change has imposed severe impact on forests through changes in the phenology, rate of growth, species distribution and composition and forest degradation through permafrost. The situation would be further worse in the twenty-first century. For instance, trees of boreal biome will act as invasive species for arctic biome. On the other hand, evergreen vegetation of conifers would move towards larch forests of deciduous nature. However there is a knowledge gap in terms of vegetational change on lowland tropics influenced by climatic variability. From a faunal perspective, climatic variation would also severely impact directly and indirectly due to loss of suitable habitat (IPCC 2014).

Vegetation of coastal zone is also under severe stress of climate change. It has been observed that mangrove plantation of the coastal region cannot withstand

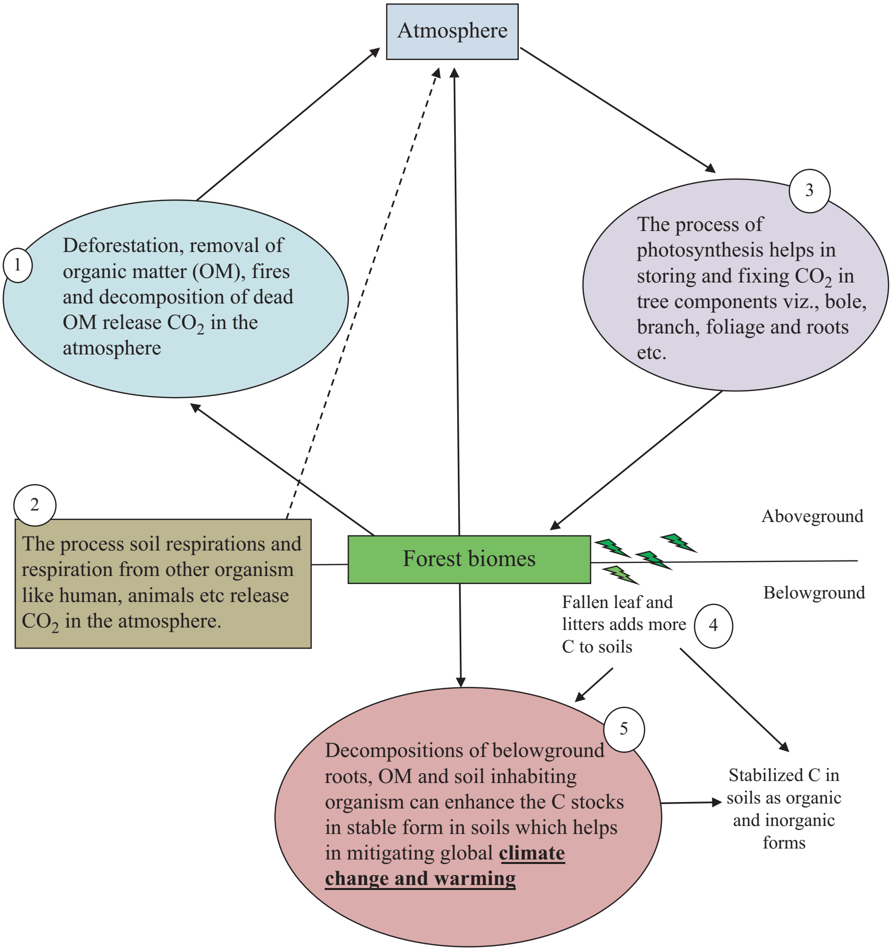

Fig. 1 Carbon flow in forest biomes and climate change mitigations. (Berndes et al. 2016)
Note: Box nos. 1 and 2 represent C stabilizations in the atmosphere, and box nos. 3, 4 and 5 show C stabilizations in both forest vegetations and soil (SOC)

under changing climate until and unless they migrate inward. Further swampy and marshy vegetation of coastal freshwater would become highly vulnerable due to salt water intrusion. Besides vegetation coral reef would be largely affected through such events (IPCC 2014).

The major impact of climate change on forests can be reflected through various events such as migration of vegetation towards higher elevation and towards pole (Ogawa-Onishi and Berry 2013; Telwala et al. 2013). Changes of biome composition, exotic plants invasion from different biomes and occupying understorey of forests are the major consequences (Singh et al. 2012). As per research reports, arctic tundra biome has reflected expansion of shrub plantation (Blok et al. 2011).

Table 1 Interaction between extreme weather or various climatic variables and tree species

Extreme weather and climatic variables	Reported tree species	Experiment conditions	Response type	References
Rising CO_2 + high temperature	Mongolian oak (*Quercus mongolica*)	Demonstrated in controlled environment, i.e. controlled chamber	+	Wang et al. (2008)
Rising CO_2 + climate-mediated low moisture stress in soil	Cork oak (*Quercus suber*)	Controlled environmental conditions	+	Faria et al. (1999)
Rising CO_2 + climate-mediated low moisture stress in soil	Red gum tree (*Eucalyptus macrorhyncha*)	Controlled environmental conditions	–	Roden and Ball (1996)
Rising CO_2 + high temperature stress	White gum tree (*Eucalyptus rossii*)	Controlled environmental conditions	–	Bassow et al. (1994)
Rising CO_2 + nutrient enrichment condition	Paper birch (*Betula papyrifera*)	Demonstrated in controlled environment, i.e. controlled chamber	Neutral	Zhang et al. (2008)
Rising CO_2 + climate-mediated drought conditions	Subabul (*Leucaena leucocephala*), a novel N-fixing tree	Demonstrated in controlled environment, i.e. controlled chamber	+	Polley et al. (2002)
Rising CO_2 + climate-mediated drought conditions	Sweet acacia tree (*Acacia farnesiana*)	Demonstrated in controlled environment, i.e. controlled chamber	+	
Rising CO_2 + climate-mediated drought conditions	Honey mesquite tree (*Prosopis glandulosa*)	Demonstrated in controlled environment, i.e. controlled chamber	+	

Note: + and – indicate positive and negative responses, respectively

Actually climate governs the structure, distribution and ecological dynamics of forest ecosystem. As a consequence of it, distribution of forest types, C emission and stocking and climate change are considered to be an integrated process. Forests can act upon climate change both positively and negatively. In a positive sense, forest is a principle tool for climate change mitigation as it acts as a global C sink. On the other hand, depletion of forest cover may cause increment in the level of atmospheric CO_2.

3 Forest and Climate Change: Global Scenario

Globally CO_2 as GHG is directly emitted through burning of fossil fuel, and other GHGs such as nitrous oxide and methane are produced through removal of forest cover and cultivation practices (Yohannes and Mebratu 2009; Meena et al. 2018). The major cause of the increasing concentration of atmospheric CO_2 includes deforestation activities under tropical climatic conditions. This therefore promotes warming of the earth's surface. Fossil fuel consumption and removal of forest cover act as two key drivers for climatic alterations causing a significant level of livelihood insecurity (Ackerman 2009).

As per the IPCC recommendation, the average temperature may increase approximately 6.5 °C at the end point of the twenty-first century (IPCC 2007). Human civilization history revealed unprecedented growth of climate change phenomenon is directly associated with GHG emission (IPCC 2013). The overall impact of such mega events includes all-round destruction of bioresources, ecological integrity and economic progress (IPCC 2014).

It has been found that the integrated system of forestry, agriculture and different land uses shares a significant amount of GHG emission. As per IPCC (2013) recommendation, it was noted that human activities contribute significantly towards GHG emission. The most probable consequences due to such events are glacier melting and atmospheric warming at the polar region, leading to the rising level of sea (IPCC 2014).

Climate change and forests have revealed miscellaneous results from global perspectives (Table 2). For example, forest plantation and natural regeneration have promoted the increase of forest cover in various countries such as China, European countries along with Latin America and Caribbean countries (FAO 2010). The effect is negative in case of tropical countries of Asian subcontinent, African subcontinent and Pacific regions along with parts of Latin America because of agriculture expansion along with continued deforestation (FAO 2009).

Globally it is a necessity to prepare a database regarding possible threats of climate change towards forest ecosystem (Millar et al. 2012). Besides forests it has been observed that water, health, genetic pool and cultivation practices come under severe threat of the climate change (Ahenkan and Boon 2010). In this context forests harmonize between maintaining integrity in the earth and ecological systems and promoting socioeconomic upliftment for forest-dwelling community. Forest also tends to combat natural hazards to a larger extent.

4 Impact of Climate Change on Forests

Climatic variation can be properly defined through various consequences such as changes in the temperature regimes, increment in the level of atmospheric CO_2, alteration in the precipitation pattern and alteration in the frequency of occurrence of extreme events. All these events have long-term impact on forest in the form of extending growth period, changes in composition of insect species and alteration in

Table 2 Climate change impacts on different tree species in various regions

Tree species	Region	Climatic effects/ responsible factors	Results	References
Oak tree (*Quercus* species)	Oklahoma, USA	Severe drought under extreme climate	Declining population of oak	Rodriguez-Calcerrada et al. (2017)
Ash tree (*Fraxinus* species)	Northwestern Pennsylvania, USA	Severe drought and freezing climate, insect outbreak events	Dieback and widespread mortality	Royo and Knight (2012)
Scots pine (*Pinus sylvestris*)	Spain, southwestern Europe	Winter chilling temperature and extreme cold climate	Dieback, needle loss and large-scale mortality	Camarero et al. (2015)
Cotton tree (*Gossypium* spp.)	Southern California	Rising temperature and extreme hot climate	Emergence of pest like pink bollworm (*Pectinophora gossypiella*) causes death of the tree	Henneberry (2007)
Citrus fruits (*Citrus* spp.)	Southeastern Australia	Rising temperature and extreme hot climate	Emergence of *Epiphyas postvittana* (light brown apple moth)	Thomson et al. (2010)
Apple pear (*Pyrus pyrifolia*)	Rajgarh, Himachal Pradesh, India	Rising temperature as global warming	Diversion of species in area as from apple to peach	Anonymous (2008)
Apple tree (*Malus pumila*)	–	Rising temperature as global warming	Affect reproductive biology as lowering in the fruit bud formation and small flower	Chadha and Awasthi (2005)
	Kullu and Shimla districts of Himachal Pradesh, India	Change in temperature	Diversion of species in area as from apple to kiwi	Gulati (2009)
Sal (*Shorea robusta*) and Gurjan (*Dipterocarpus turbinatus*)	Southeast Asia	Climate change and deforestation	Threatened and loss of species	Deb et al. (2017)
Mangosteen (*Garcinia indica*)	Northern Western Ghats, India	Wide temperature variation under changing climate	Threatened and decline in suitable distribution of species in Western Ghats	Pramanika et al. (2018)

the frequency of forest burning. Prevalence and outburst of pests are secondary problems which are aggravated through climate change. As per IPCC report (2007), 33% of global diversity of species are facing the fate of depletion through climatic perturbations, as reflected from mountain and tropical ecosystems.

Global warming has imposed its positive impact through higher growth of trees with prolonged duration of growth (Lucier et al. 2009). Such facts reflected positive correlation with high temperature regime and elevated CO_2 level. Negative impacts include shifting of vegetation, changes in successional pattern, abiotic stress in terms of drought and heat stress for forests plants leading to high mortality globally (Allen et al. 2010). All these consequences are the outcome of intense change in climatic conditions. Humans are just aggravating the problems in the form of releasing ozone-depleting substance, emission of nitrous oxide, spread of insect species, fragmentation of habitat and forest fire (Bernier and Schone 2009). The rising level of sea due to warming of the earth's surface is engulfing tidal freshwater as well as marine forest to a considerable extent (Di Nitto et al. 2014).

As per the records, future prediction of climate change will tend to have different dimensions of ecological impact. The major impact includes widening or narrowing of species ecological amplitude, shifting of ecological zones and alteration of forest productivity (Campbell et al. 2009). Depending upon the forest type and vegetation structure, it has been found that forest ecosystem such as boreal forests, mangrove forests, alpine biome, tropical deciduous forests and forests under Mediterranean climate is severely affected due to climate change (Bernier and Schone 2009; Huntingford et al. 2013; Datta et al. 2017) (Fig. 2).

4.1 Climate Change and Vegetation Growth Trait

Alteration in the climatic elements imposes its impact on energy flow, nutrient cycling, productivity, diversity, ecological process and C balance of forests. Time is also a very important factor from physico-chemical and biological perspectives (D'Aprile et al. 2015). Amplification of the negative impacts may be a serious consequence for managing forests in a sustainable way under climate change. Climatic elements tend to influence the growth of forest in a significant way in the form of increasing and decreasing pattern in the growth periods (Merian et al. 2013). Climatic perturbation through rainfall and temperature regimes is a key factor that regulates growth of trees (Sedmak and Scheer 2015). Under traditional system of forestry, emphasis is being given on yield attributes such as wood content, log volume and regeneration capacity which do not often consider the climatic irregularities, affecting tree growth as well as pattern of growth on time scale. Such type of approaches is unable to predict the optimum growth period for forest trees and factors responsible for that. It has been found that silvicultural and harvesting practices promote the emission of C based on temporal variability.

Time management could be an effective tool in order to promote forests to mitigate and adapt to climate change under changing scenario (Lafortezza et al. 2013). Two crucial factors that regulate the energy balance on the earth and universe

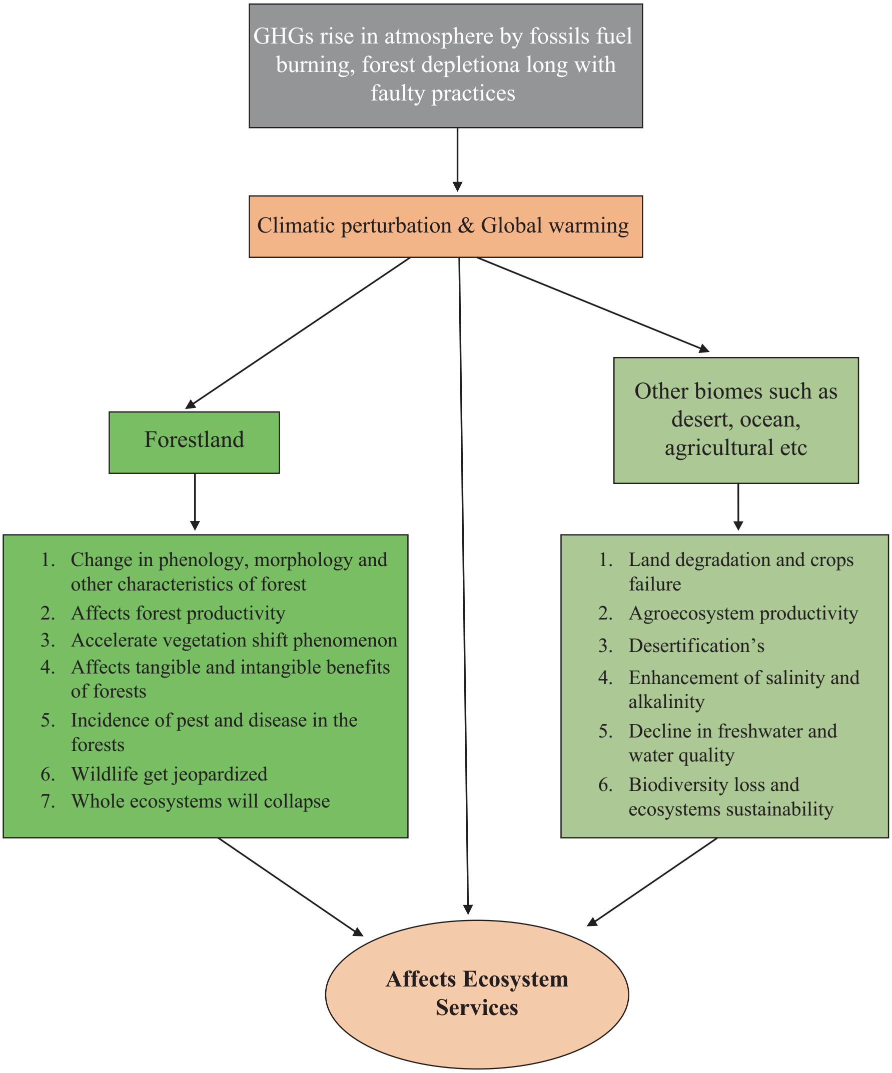

Fig. 2 Forests and other biomes under changing climate. (Berndes et al. 2016; Singh et al. 2012; Campbell 2009; Bernier and Schone 2009)

include the diversity of organisms and climate. Biodiversity is a consequence between changes at the molecular level along with changes in the evolutionary perspective leading to maintain the equilibrium between the earth and outer space. The key issues of the present decade include the increase in the ambient CO_2 level. The most obvious consequences of it include global warming and alteration in C cycle.

The impact of climatic variability has a strong influence over forest growth at local level (D'Aprile et al. 2015). Growth responses vary according to climatic perturbations (Pretzsch et al. 2014). The interaction between climatic changes and growth of forest can be used as a strategy for SFM.

4.2 Climate Change and Vegetation Productive Trait

Productivity of a forest ecosystem depends upon the temperature, precipitation and availability of nutrients. However the response of forest trees may vary on the basis of their adjustment to changing climatic conditions (Das 2004; Jhariya 2014). Alteration in the temperature regimes affects the key processes of forest ecosystem which include nutrient cycling, litter decomposition and root dynamics for nutrient uptake along with other associated dynamics of forest ecosystem (Norby et al. 2007). Increase in the temperature may be advantageous for vegetation during colder periods and may be disadvantageous during dry season (Garrett et al. 2006). Under increasing temperature condition, moisture level in the forest would be severely affected due to alteration in the temperature and precipitation pattern. Higher temperature tends to promote evaporative process and evapotranspiration process which tends to reduce the water use efficiency of vegetation and alters the salt water balance within the plant system leading to poor growth and development (Mortsch 2006).

Extended period of warmer season may promote moisture stress and drought condition which may impact on growth of forest trees depending upon the vegetation characteristics as well as the nature of the soil (Mortsch 2006). It has been found that young stands of vegetation in the form of saplings and seedlings are much more vulnerable towards climatic changes than mature trees due to the storage of metabolite at higher level.

Plants with shallow root growth under shallow substratum would be severely affected by the moisture deficit. On the other hand, plants with deep fibrous root are not that much vulnerable in terms of growth due to water stress. Research reports reveal stress factors such as moisture and drought increase the vulnerability of vegetation towards pest outbreaks and diseases. Even they may become more susceptible towards events such as forest fire. Hogg et al. (2008) reported the reduction in productivity and death of *Populus tremuloides* (quaking aspen) species found in the western part of Canada. Negative impacts include defoliation and boring of woods by pathogenic organisms. Drought has induced stand replacement and growth retardation in case of *Fagus sylvatica* (European beech) in Spain and other parts of Europe (Jump et al. 2006).

Ambient level of CO_2 promotes growth and water use efficiency in vegetation in the absence of other limiting factors such as nutrient and water. Such event takes place up to a certain limit beyond which the positive impact may turn towards negativity (Stone et al. 2006). Morphological changes can take place under elevated level of CO_2. Changes include increment in the number of leaves, leaf area, more thickness of tree girth and branches, etc. (Garrett et al. 2006). It has been found that changes in floral structure and forest dynamicity are based upon the nature of species and its associated environmental conditions in response to increased CO_2 level

(Bauer et al. 2006; Varma et al. 2017). Research reports reveal higher ground-level concentration of ozone may increase the vulnerability towards pathogen and lesser productivity (Karnosky et al. 2005). Another finding includes increment of growth and productivity for boreal forest at higher level of nitrous oxide (Stone et al. 2006).

The productivity of a forest ecosystem is a very important parameter for growth and development. It has been observed the productivity rate varied significantly depending upon geographical area, species composition, age, structure of forests, lithology, CO_2 concentration and nutrient availability (LeBauer and Treseder 2008). Under climate change scenario, water stress reduces plant growth, and under surplus conditions, the growth may be ceased as revealed for CO_2 and N (LeBauer and Treseder 2008; Ollinger et al. 2008). The productivity rate of forests increases as the temperature increases which may be due to the higher presence of CO_2 (Fig. 3). The condition is a little bit different under tropical condition where changes take place seasonally, and productivity rate may decrease after C saturations (Feeley et al. 2007). Water scarcity may also act as another factor to cause decline in productivity (Malhi et al. 2008).

Overall the climate change has multidimensional impact (Table 3) over the forest ecosystem through alteration in the species composition, productivity rate, growth rate, growth and yield attributes and also the site physical characteristics (Williamson et al. 2009). Further increase in the temperature may promote forest productivity up to a limit and then show further decline (Fischlin et al. 2007). The seasonal pattern of climatic change may impose a bigger impact over forest ecosystem than an annual impact on a long-term basis (Bugmann and Pfister 2000).

4.3 Climate Change and Vegetation Shift Scenario

Climatic variation is a mega event in terms of changes in species composition within forest ecosystem. On a long-term basis, climatic variation has severe consequences over forest species composition. Depending upon the climatic pattern of an area, there are shifting paradigms from one vegetation type to another just like ecological succession process. Species distribution changes take place on latitudinal and altitudinal extremes under the influences of changing climate. Research reports reveal shifting forest vegetation towards higher altitudinal area in response to global warming (Menendez 2007). Lenoir et al. (2008) reported long-term study of altitudinal distribution of forest vegetation which revealed a paradigm shift towards upward direction at the rate of 29 meter per decade. Climate change alters spatial pattern in relation to forest flora (Lenoir et al. 2008).

Among the vegetation types, short-day plants were found to relocate in the form of altitudinal shift, whereas long-day plants such as hard woody species reflected lesser impact of climate change. Such changing pattern would alter the entire configuration of forest ecosystem. Climatic extremes such as drought-induced stress in oak species have been reported in Spain, Portugal and Italy and their subsequent dieback (Resco de Dios et al. 2007). Research findings reveal migration of forest species at higher altitude and even extinction of species (DoEST 2012). Research

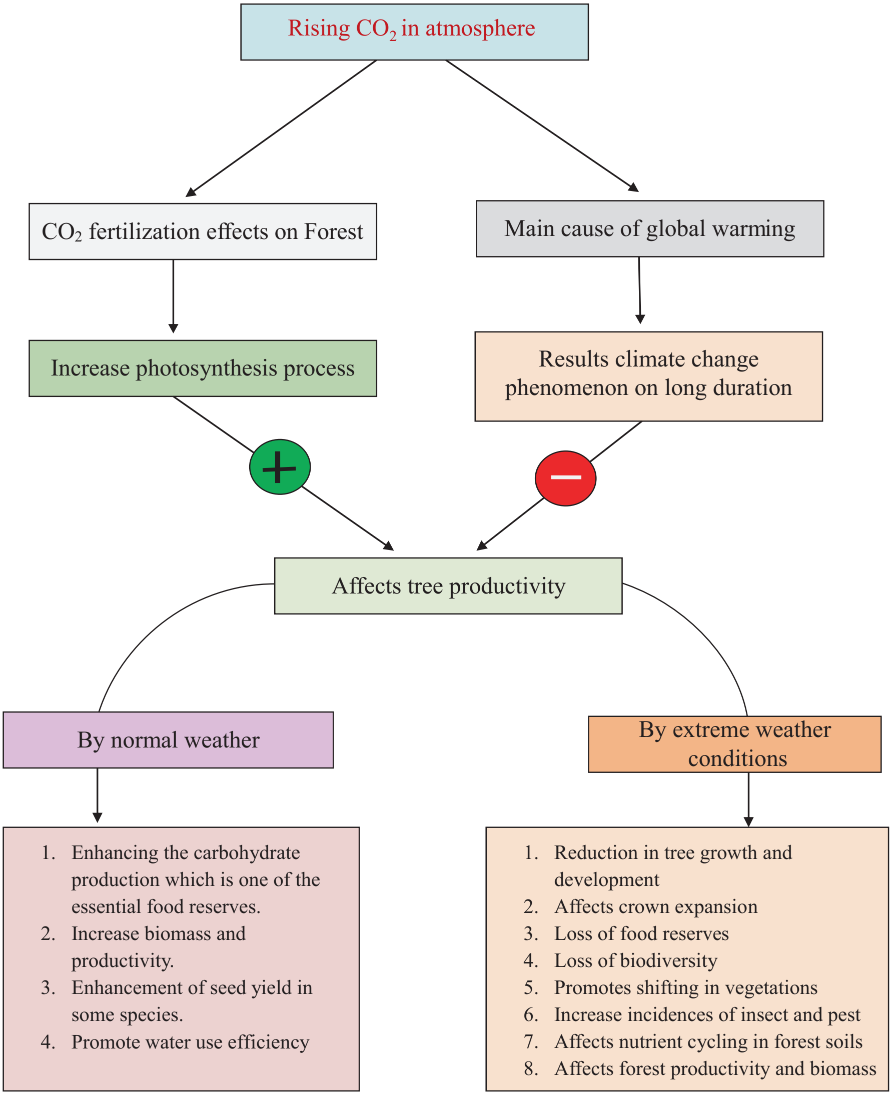

Fig. 3 Rising CO_2 and tree productivity. (Ramirez and Kallarackal 2015)

reports reflect *Pinus longifolia* (pine), *Aconitum heterophyllum* (Indian Atees), *Woodfordia fructicosa* (Dhawai) and white Himalayan lily (*Lilium polyphyllum*) showed upward migration at higher altitude within a century (DoEST 2012). In economic sector orchard plantation has also reflected such shifting in terms of lower economy output causing problems for livelihood. Interesting studies reflect species invasion or species replacement of *Quercus leucotrichophora* (Banjh oak) to *Pinus roxburghii* (chir pine). Further it has been observed species such as shisham

Table 3 Elevated CO_2 impacts on biomass, productivity and other vegetative growth varying forest in world

Tree species	Environmental factors	Responses	References
Mixture of three species, viz. *Fagus sylvatica* (common/European beech), *Betula pendula* (silver birch) and *Alnus glutinosa* (black alder)	Elevated CO_2	Enhancement in above ground biomass from 15.2 ± 0.6 to 20.2 ± 0.6 kilogram per m^2, i.e. 17% increment	Smith et al. (2013)
Tree species like silver birch (*Betula pendula*)	Elevated CO_2	Leaf area index (LAI) was increased by 37%	
Tree stand of loblolly pine (*Pinus taeda*) and sweetgum (*Liquidambar styraciflua*)	Elevated CO_2 of 550 part per million	Enhancement of net primary productivity by 23 ± 2%	Norby et al. (2005)
Populus tremuloides (aspen), *Acer* species (maple) and *Betula pendula* (birch)	Elevated CO_2	Enhancement in leaf area index value	Oksanen et al. (2001)
Black poplar tree (*Populus nigra*)	Elevated CO_2	Productivity enhanced by 225%	Gielen et al. (2001)
Some conifers tree species	CO_2-enriched, i.e. elevated CO_2	Positive impact on biomass as enhanced by 130%	Saxe et al. (1998)
Loblolly pine (*Pinus taeda*)	Raised CO_2 level	91% increased seed weight	Hussain et al. (2001)
Natural stand of oak tree-based forest in Florida comprised *Quercus myrtifolia* (myrtle oak), *Quercus geminate* (sand live oak) and *Quercus chapmanii* (Chapman oak)	Elevated CO_2	Significant effects on acorns resulted in higher production	Stiling et al. (2004)
–	Elevated CO_2	Enhancement in root-to-shoot mass ratio	Oechel and Strain (1985)
Tulip poplar (*Liriodendron tulipifera*)	Elevated CO_2	Neutral effects on root-shoot ratio	Norby et al. (1992)
Tree species like white poplar (*Populus alba*), cottonwood poplar (*Populus nigra*) and Canadian poplar (*Populus euramericana*)	Elevated CO_2	Affects belowground production as enhancement in belowground biomass up to 76%	Lukac et al. (2003)
–	Elevated CO_2 of 550 part per million	Fine roots biomass increased by double figure	Norby et al. (2004)
Oak tree stand comprised *Quercus petraea* (sessile oak) and *Quercus robur* (common oak) of Northeastern France	Elevated CO_2	Basal area increment	Becker et al. (1994)
Tropical forests	Elevated CO_2 of 550 part per million	Significantly increased NPP by 35%	Collatz et al. (1991)
Temperate forests	Elevated CO_2 of 370 part per million	Significantly increased NPP by 26%	

(*Dalbergia sissoo*) and deodar (*Cedrus deodara*) revealed population decline due to the influence of climate and human (DoEST 2012).

Parmesan (2006) reported the migration of alpine vegetation beyond their distribution range. Vegetation shift has also taken place in Siberia, Canada and New Zealand, and northward migration has been reflected in the eastern part of Canada and Sweden. Montane rainforest under tropics reflects shifting paradigm to higher altitude (Jones et al. 2008). Such shifting paradigm may not only regulate by temperature but also by seed dispersal ability into newer regions which poses suitable climatic elements with anthropogenic influences for species dispersal and alteration in the disturbance regimes (Monserud et al. 2008).

Alteration in the quality of ecosystem has imposed significant change in forest ecosystem. Ecosystem change includes alteration in the rainfall pattern, abnormality in dry and wet period and alteration in characteristics of soil with subsequent change in the sea level. Such events steal out the adaptability of forests species under changing environment. It has been observed that regeneration potential, age structure, species diversity and forest dynamics significantly alter (CCFM 2009). The age structure of forest reveals that seedlings and older plantation are much more vulnerable towards climate change than younger ones. In the era of climate change, forest vegetation reflects three modes of responses. Firstly, on the basis of their ecological niches, forest trees migrate spatially. Secondly, wider adaptability in their habitat range in forestland. Thirdly, the worse situation includes the total extinction of species (Aitken et al. 2008). To predict the ultimate fate of forest tree species, one needs detail knowledge at the genetic level to community level with ecological functioning on spatial basis. Time-bound analysis includes proper knowledge regarding growth cycle and traits of forest vegetation.

Jorgenson et al. (2001) reported that degradation of permafrost in Alaska has caused vegetation shifting into bogs and fens from birch forests. Global warming-induced depletion of permafrost has led to conversion of densely populated bogs to non-populated fens in western Canada (Vitt et al. 2000). Climatic perturbations even show their negative impact on *Chamaecyparis nootkatensis* (Alaska yellow cedar) type of hardy species in the bane of extinction as high as up to two lakhs hectare geographical range (Hennon et al. 2008).

4.4 Climate Change: C Dynamics and Forest Soil

Interrelationship between C assimilation and climate change scenario has the biggest implications for sustainability of forest ecosystem. More concentration of CO_2 assimilates in vegetation, the more will be the reduction in ambient CO_2 level, and as a consequence, the global warming phenomenon can be checked. Such mechanism has been widely adopted by the tropical countries to participate in the C trading process. Simultaneously the increase in the C stock and reduction in ambient CO_2 level take place. Economic policy designing in the sustainable management of forests has already being initiated at tropical conditions as well as other foreign countries (Sanchez Chavez 2009).

Under the event of climate change, possible inevitable facts include rising temperature and long dry spell of climate with gradual increment of ambient CO_2 concentration which significantly reduces C storage potential of forests and converts them as a source of CO_2 emission (Ollinger et al. 2008; Nepstad et al. 2008; Yadav et al. 2017a). C sequestration and productivity are intricately interrelated with each other. Normally increasing temperature leads to lesser C storage on short time span basis. However the situation may be changed in case of temperate climatic conditions.

Climate change has serious consequences in relation to nutrient dynamics, soil C level and soil moisture level. It has been revealed that C storage in soil makes them a large potential source of GHG emission. Climate change imposes significant impact on soil resources by various ways. Bradley et al. (2005) reported various modes of depletion of soil resources due to climate change. Temperature increase would increase the rate of soil respiration leading to depletion of soil C. Further dry spell due to lack of rainfall stimulates evapotranspiration at a higher rate which further causes loss of soil C. Alternatively it was observed the higher level of tree productivity due to higher litterfall on forest floor is a consequence of increment in ambient CO_2 level.

Further warm temperature may produce higher temperature in soil surface due to higher rate of soil respiration which may enhance soil C level. Higher growth rate of trees may also prove to be negative in terms of depletion of nutrient, soil acidification and reduction in productivity level at the long term. Alteration in soil C and nitrogen (N) level significantly influences C/N ratio which may create problem for understory vegetation of forestland. Climatic extremes in terms of heavy rainfall promote higher soil erosion. High temperature along with heavy rainfall may cause depletion of dissolved organic carbon (OC) of forest soils. Bradley et al. (2005) mentioned interrelationship of mycorrhizal species, ground vegetation and host plants is determined by the level of atmospheric CO_2, pollution and moisture content of soil.

Considering changing climatic scenario SFM is the need of the hour. Adaptive strategies and mitigation policies need to be formulated and implemented at the grassroot level. In this connection plantation of leguminous trees would be a fruitful option for nutrient building of forest floor. Leguminous species through biological N fixation mechanism improves the N content of the soil. Further they also promote growth of soil microbial biota (Banerjee et al. 2018; Jhariya et al. 2018; Ashoka et al. 2017). To restore soil quality under the era of climate change, biological processes are the most suitable answer. In this path plantation of fast-growing species giving higher biomass input is another suitable technique which may improve the soil C stock. Climate change often produces climatic extremes such as heavy rainfall which may erode the top soil completely. Proper forest cover may help to combat such problem and help to conserve soil resource (Jhariya et al. 2018; Banerjee et al. 2018).

5 Forest: Climate Adaptation and Mitigation

Combating changing climate involves both adaptive and mitigatory measures. Globally a harmonized approach is required between mitigatory and adaptability towards changing climate (IPCC 2002). IPCC has addressed this particular issue from biodiversity conservation perspective. Adaptation includes responses of biota towards climatic perturbations in order to reduce hazards and negative consequences and generate more beneficial opportunities. Three modes of adaptation have been recognized from climate change perspectives such as adaptation in perception of climate change, people's participation and towards scientific and systematic adaptation approaches (IPCC 2002). The site of adaptation may extend up to the individual basis starting from ecosystem, community and population. Adaptation has both long- and short-term outputs. On long-term basis, the impact would reduce GHG emission reduction, and short-term consequences include the benefits to the implementing countries.

Climate change mitigation is recognized as a major issue worldwide from the climate convention and Kyoto Protocol discussions. UNFCCC aim towards GHG emission reduction, facilitate the negative consequence reduction towards human civilization in relation to climatic variables. Alone mitigation cannot supersede the changing climate. Climate change is a phenomenon which obviously has negative consequences either on a short-term or long-term basis. Therefore, mitigation should be accompanied by adaptation strategies (Bruce et al. 1996).

Forest vegetation tends to combat the changing climate under increasing C pool within soil-plant system and also provides a secondary path for generation of fossil fuel energy. Species also promote C in different plant components. SFM is an integrated approach in the area of climate change mitigation which aims towards more biomass production and therefore increase in the C stock (Fig. 4). There is a significant variation in C storage capacity in various regions of the world. The time frame for mitigating climate change is a crucial factor. Young vegetation stand has higher C sequestering potential than the old and degenerating stand. Also in mature stand, the C sequestration reaches saturation limit. Therefore, mitigation of climate change can be mediated through growing stock of population. On time frame increase in the forest cover through afforestation process leads to further C sequestration and climate change mitigation.

Three broader approaches were considered during climate change mitigation strategies. It includes management of C stock and conservation, increase in the area of C sink and exploring suitable alternatives for fossil fuel (Brown et al. 1996). C emission reduction with inhibition of deforestation is the primary countermeasure towards climate change. Secondly, reforestation practices in the degraded land to trap atmospheric CO_2 are another feasible measure towards climate mitigation. Mitigation strategies vary depending upon the land-use pattern, soil quality and policies of landholding which is interrelated towards using forest for resource purpose with socioeconomic development.

Optimum strategy development often leads to contradiction in the form of timber harvesting under the aim of increasing C stock. Apart from these, natural disasters

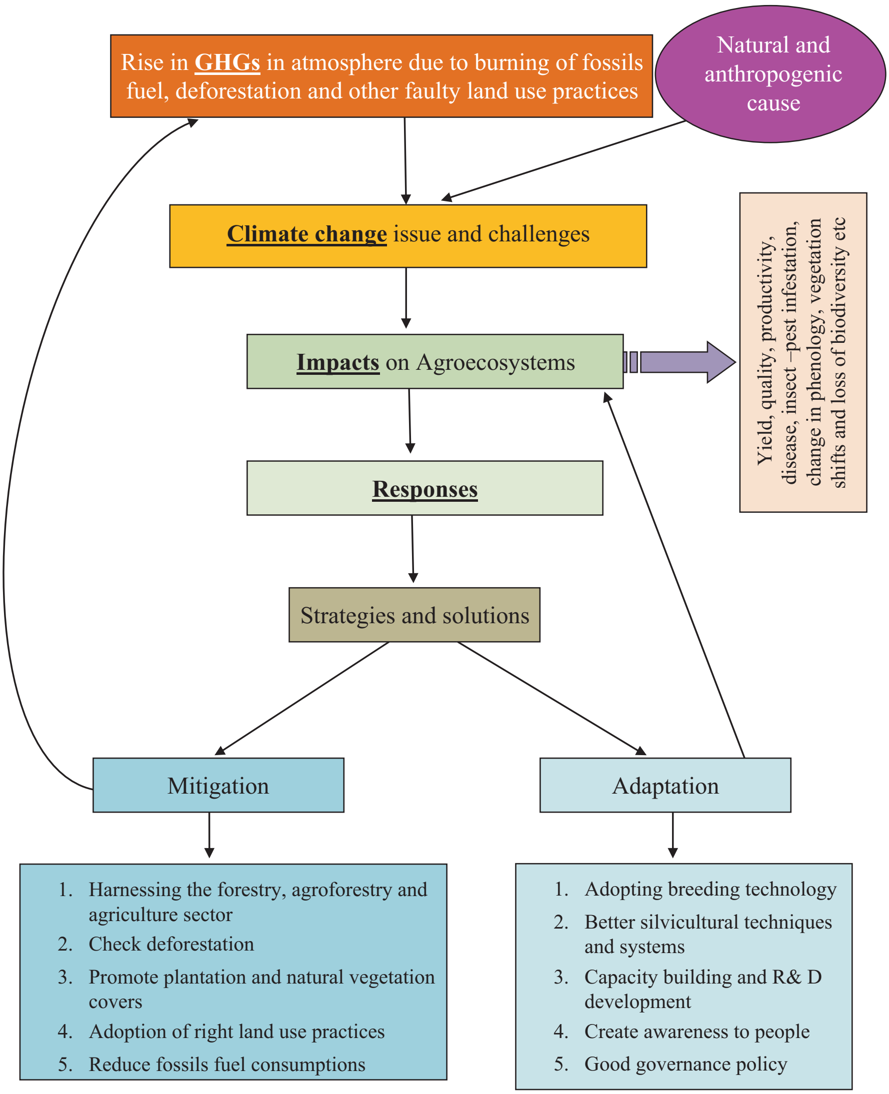

Fig. 4 Climate mitigation and adaptation through forestry. (Patosaari 2007; Keenan 2015)

also influence the C stock of forests. Some sustainable strategies need to be reoriented at the national and regional level to promote mitigatory measures towards climate change. This important agenda includes reducing deforestation, improving productivity of forests, checking peatland drainage, reducing damage to forests by storm, reducing the impact of natural calamities and reducing wood consumption through finding suitable energy alternatives. Development in the rural sectors should be harmonized with mitigatory measures for climate change. It has been reported that wood has low C footprint due to their higher efficiency of C utilization during their production and processing steps. Wood is highly efficient in this matter as it can be used as bioenergy even after the product life. It should be incorporated at national policies to promote the alternative use of wood in order to combat climate change.

From global perspectives, the adaptation strategies need to be varied in order to promote sustainable adaptation depending upon the conditions of the local environment. This is true for the forest of Europe. Overall the necessary adaptation measures need to be designed for each specific region. The target sectors include regeneration of forest, stand tending and thinning, sustainable harvesting, planning at the forest management level, forest protection measures and silvicultural schemes, good communication and infrastructure development, nursery and breeding of trees and overall suitable forest policy.

The major hindrances in this process include major uncertainty of the climate change phenomenon, lack of proper adaptation strategies for most countries, a huge gap in the field of vulnerability assessment and work at the grassroot level. Lack of adequate training of the individuals involved in such task and funding resources and last but not the least public awareness regarding these issues, which is the biggest challenge.

From the perspective of adaptation towards climate change, it has been found that limited approaches have been addressed towards studying the local impact of climate change due to its uncertainty. Therefore, there is an urgent need to formulate experiment and execute suitable adaptation policies. In this connection, ecosystem resilience is a suitable approach as it is the inherent capability of ecosystem to prevent change and alteration. Strategies should be integrated between biodiversity maintenance and social values along with economic output (Raj et al. 2018b). Studies regarding adaptation option under variable level of disturbances need to be further researched.

6 Key Issues and Challenges for Forests Towards Climate Adaptation

Disturbances in the forest ecosystem are influenced by the climate of a region. For example, species outbreak in the form of ecological invasion, problems of pest and disease infestation and occurrence of natural calamities such as drought, fire, landslide, etc. can alter the structure, function and dynamics of forests (Dale et al. 2001; Jhariya and Yadav 2017; Meena et al. 2015). The susceptibility of forests towards disturbances may change depending upon the climatic conditions through increase forest fire, frequent occurrence of natural calamities and other such perturbations (Mortsch 2006).

Reports of Gopalakrishnan et al. (2011) reveal nearly half of India's forests areas are very much susceptible towards climate change. Areas include Eastern Ghats, upper Himalaya, north of Western Ghats and central part of India. Such findings are further supported by Chaturvedi et al. (2010) who report the changes in forest types can take into account up to 77%. Such types of impact overall are highly deleterious for forest ecosystem due to the integrated system of forest, disturbance regimes and climatic elements. These factors can increase the severity of the others in terms of structural change and degradation of forest area. For example, it has been observed that forest infested with pine bark beetles becomes highly susceptible to natural calamities such as the Hurricane Mitch in 1998. The infestation of these beetles promotes higher mortality in tree which simultaneously increases fuel loads and then risk of wildfire.

All these impact have wider dimension over the forests. Whatever may be the impact through ecological events and natural calamities, the mostly influenced part includes forest economy (FAO 2005). The total forest economy would change due to higher competitiveness as well as changes in the forest structure and composition due to climate change. Improved social and environmental vulnerability includes changes in ecosystem services, conservation services, risk in livelihood security and other sociocultural problems.

The IPCC (2002) reports harmony between mitigation and adaptation of climate change involving negative consequences of changing climate, exploring possible solution towards mitigation of climate change. While going for mitigation and adaptation towards climate change, one needs to consider some of the key important facts. Firstly, one needs to look for the hazardous impact of mitigatory strategies that may put forest ecosystem into vulnerable condition. Secondly, different strategies can be incorporated in the policy matter of mitigation aiming towards reduction in vulnerability. It has been found that projects also contribute towards vulnerability reductions, conservation of biodiversity, habitat protection and sustainable management of forests. Adaptation strategies such as urban forestry, climate-resilient practices and conservation approaches contribute significantly towards mitigating climate change. Proper harmonization within adaptive and mitigatory measures that reduce the negative cost caused by the changing climate and provide secondary benefits needs to be designed. The problem of forest degradation is further aggravated through population explosion, pasturing activity and many other factors. Such problems should be minimized at the grassroot level to achieve sustainability.

Some of the major challenges associated with adaptation and mitigation of climate change include the following:

- The complex nature of tropical forests
- Different land-use patterns and prevailing landholding policies
- Reducing economic viability considering ecological standpoint
- Decline in the production of tropical forests
- Legal enforcement and protection
- Efficient functioning of the global degradation process such as deforestation, loss of biodiversity, etc.
- Malfunctioning of the administrative machinery of the forest sector
- Rural poverty
- Jeopardize of forests in the name of development
- Lack of adequate database
- Improper political will

Lack of funding
Knowledge gap regarding functional role of forests towards mitigation of climate change
Shortage of staff
The corruption prevailing in the forestry sectors

In the present context, the view of adaptation towards climate change includes finding out the advantage of benefits that occurs due to change (Levina and Tirpak 2006). In the present context, the underlined principles of SFM address that the issue of climate change needs to be understood. In most of the cases around the world, proper implementation of SFM strategies often limits the climate change adaptation process (Innes et al. 2009). Management of forest department needs to integrate approaches on spatial and temporal scale to address the future risks. Key climate change mitigation strategies at the present era include more utilization of wood as bioenergy and incorporation of wood as a material for construction activities and industries. The changing scenario of urbanization is putting pressure on rural people to reduce their capacity in labour work aiming towards forest management (Ince et al. 2011).

7 Sustainable Forestry Practices and Climate Change

Combating the changing climate is the biggest issue in the entire world at the present century. One simple way to do so includes implementation of proper sustainable forestry practices. By the term sustainable forestry, we mean specific ecofriendly approaches to increase forest cover through reforestation, afforestation, agroforestry practices and improved silvicultural schemes. Such approaches increase the C sink of the world. Another focus should be given on converging degraded wastelands into forested land. Proper land-use practices in the form of agroforestry, farm forestry, extension forestry and social forestry may further promote or increase the area of C sink, thus also helping to reduce the ambient CO_2 concentration in the atmosphere (Jhariya et al. 2015; Singh and Jhariya 2016; Verma et al. 2015).

Results revealed that wood from sustainable management of forest in European Union revealed lower C footprint in their entire lifetime (0.9 t of CO_2 per cubic meter). Wood products can be efficiently recycled which gives suitable substitution for fossil fuels. This therefore causes reduction in the level of C (2.1 tons) due to lesser energy requirement for various activities. Policies related to forestry and alteration in land utilization and land-use pattern can negatively impact biodiversity and increase the risk on forests. Very interestingly climate change adaptation promotes all-round sustainable development in the form of biodiversity conservation and improvements in the C reserve (IPCC 2002).

Under traditional forest management system, activities such as cutting, thinning and harvesting may become unsuitable affecting the growth of forest tree species. It has been observed that the decrease in the growth of tree species within a vegetation stand may lead to lowering of C storage. Further higher CO_2 emission by consuming higher amount of wood mass shows negative reflection in terms of reduction in CO_2 storage potential as biomass of the forests (D'Aprile et al. 2015).

Climatic elements need to be considered in relation to harvesting of mature crops under forest ecosystem which may lead to positive trend in growth. In order to perform such activities, one needs to explore the climatic variables up to 15 years. For future perspective, climatic variable needs to be thoroughly studied to screen out the threshold value showing positive growth response for the species, type of forests and overall ecological region. Also from vegetation standpoint, attributes such as productivity, growth, biodiversity as well as C balance with respect to climatic variables at the concerned site level need to be explored (D'Aprile et al. 2015).

Holistic approach between mitigation and adaptation towards changing climate focuses on alteration in land utilization or technological development (Fig. 5). Verchot et al. (2007) mentioned that agroforestry is a fruitful option which provides both mitigatory and adaptive approach towards climate change. There are several benefits of agroforestry practices which include reduction of soil erosion, improving ecosystem resilience against natural calamities, improving soil fertility through increased OC content, reduction in crop failure mechanism and overall sustenance of biodiversity as was seen in Indonesia (Clough et al. 2011). Alternative strategy towards adaptation aims toward increasing biomass and soil organic matter (OM) content by reforestation practices, as well as the protection of ecosystem contributes significantly towards climate mitigation through sequestration of C. One interesting fact is that mono-cultivation of exotic species may promote higher C flux from the atmosphere to plant than indigenous species but simultaneously reduce the ecological functioning and biodiversity status of forests. However, this can be compromised for the sake of the C storage (Diaz et al. 2009). Under tropical condition, reforestation promotes better climate mitigation and adaptation (Sasaki et al. 2011).

Anderson-Teixeira et al. (2012) reported about the variable scenario in the high altitude as reforestation promotes warming conditions due to reduction in the albedo values. Qin et al. (2011) mentioned that energy crop plantation in the degraded or barren land has a huge potential for reduction of C emission, but it has some negative consequences in the form of conversion of C-rich ecosystem into cropland. The mechanism including reducing emissions from deforestation and forest degradation (REDD+) can reduce the potential risk of negative consequences of C emission, and therefore economic incentive structure needs to be formulated specifically (Busch et al. 2012).

Management of forest emphasizes towards livelihood generation and poverty alleviation (Larson 2011). Right over resources is a very essential thing towards promoting livelihood benefits for local community stakeholders (Macchi et al. 2008). REDD+ have been implemented focusing recognition of forest rights (Angelsen 2009). Strategic suggestions reveal that community stakeholders can bridge between climate change and biodiversity conservation (Salick and Ross 2009). It deviates from adaptation towards ecosystem as forests are being considered to be utilized as resource by the local community (Campbell 2009). However REDD+ can act effectively in timber production by the consequence of low logging activity (Putz et al. 2012). Integrated approaches such as ownership of forest

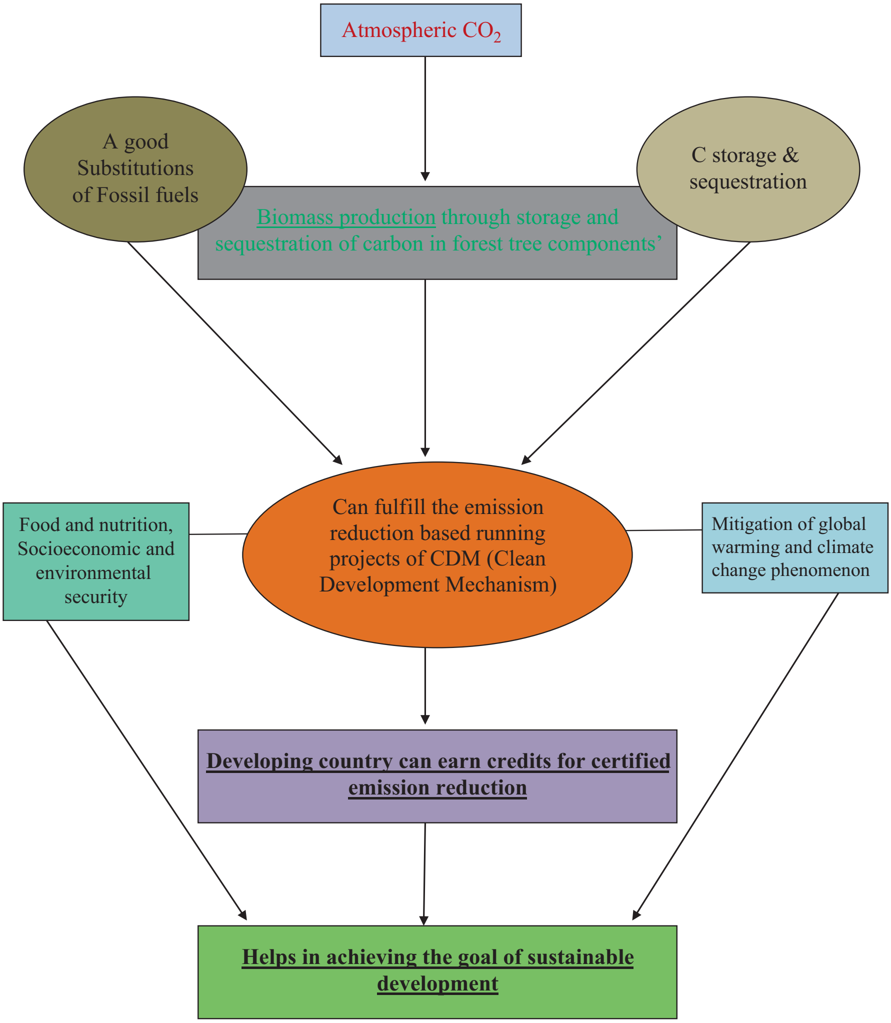

Fig. 5 Mitigating climate change and sustainable development. (FAO 2016; UN 2015, 2017; IPCC 2002; Keenan 2015; Millar et al. 2012)

products, sustainable harvesting and management and community empowerment may be the fruitful strategies (Putz et al. 2012). As per reports the higher rate of C sequestration in organically rich mangrove soil and soil of peat swamp wetland forest ecosystem may work efficiently in adaptation and mitigation by restoring degraded areas (Page et al. 2011; Donato et al. 2011).

Agriculture, forestry and other land use (AFOLU) imposes a significant role towards food crisis aiming towards sustainability. Through biogeochemical cycling of nutrients, plants uptake CO_2 from the atmosphere and N from soil and return back as biomass (below+above ground) litter and OM present in the soil. Major

GHGs such as CO_2, methane and nitrous oxide are frequently released through plant respiration, through decomposition of dead OM and through ignition. Biotic disturbances such as alternate land-use activities in the form of forestland conversion into agricultural area and grassland to pasture land further aggravate the problems of GHG emission.

A modification under AFOLU scheme includes changes or alterations in atmospheric emission of GHGs and contributing more in the soil and vegetation in the form of C stock. Alternate land-use practices in the form of agroforestry may reduce atmospheric CO_2 level and provide a suitable alternate in the form of biological products in place of fossil fuels. However, some strategies are available to combat such event of climate change in the form of changing lifestyle, preventing food wastage, altering the consumeric nature and lesser dependency towards forests from wood consumption perspectives. From the ancient time, it was observed that AFOLU played a significant role for food, fodder and fibre production globally. It also provides various ecosystem services and environmental goods for human prosperity (MEA 2005). GHG emission is a little bit lower for non-CO_2 gases due to the limited level of sources such as forest fire and wetland degradation due to water abstraction. As per the records, forestry and other land uses (FOLU) act as sources for CO_2 emission up to 33% for two centuries and up to 12% within the 9-year span of the last decade (Pan et al. 2011). The use of excessive chemical fertilizers in the modern agricultural system also contributes significantly towards climate change (Le Quere et al. 2013). As per research results, it was observed that FOLU CO_2 emission was reduced due to lowering of deforestation (FAOSTAT 2013).

8 SFM for Biodiversity Conservation and Livelihood Management in the Tropics

Forests play various beneficial roles for prosperity and growth of human civilization. It maintains hydrology, regulates hazards from natural calamities, provides economic benefits and works for social well-being (FAO 2006). Forests are the backbone of biodiversity at the global scale and also provide livelihood for more than one billion people.

SFM is an integrated approach that integrates environmental stewardship by maintaining ecological integrity through biodiversity conservation and productivity. It also takes into consideration about the various functions at various levels having impact over the global ecosystems. Climate change is such an event which does not have any single solution, and therefore multidimensional strategies are required to combat such problem. In this direction predicting climate change is a suitable option. The major focus in SFM should be addressed towards the management strategies and their influence to C cycle under the changing climate scenario and subsequently how it impacts the global biodiversity.

Forests has multifunctional role in terms of economic returns. The main output of forest in terms of economic return is wood. Apart from this forest often provides various types of non-timber forest products (NTFPs) which invariably promote livelihood security and social well-being of community stakeholders (Painkra et al. 2016). NTFPs play a significant role in the secondary sector such as fulfilling daily needs of forests dwellers, off-farm outputs and a source of income during lean period (Osman-Elasha et al. 2009). The problem of climate change would significantly affect NTFP production which in turn will impact those people who are poor and resource dependent below the poverty line and use NTFPs as income source. Such events take place under climatic irregularities and natural disturbances present in forests. Future exploration is required considering the theme of climate change and their impact over NTFPs and its socioeconomic services. Activities having economic orientation such as mountaineering and skiing in low altitude would be influenced by temperature increase. Osman-Elasha et al. (2009) reported that proper database of influences of changing climate upon recreational services needs further explorations. Very few works have been reported on this particular issue, and those which have been reported are focused at the local level. It has been reported that climate change significantly influences the forest biodiversity in Africa (Osman-Elasha et al. 2009).

Climate change jeopardizes forest ecology and socioeconomic dimension of forest ecosystem. The ecological consequence of NTFPs has got quite a bit of uncertainty, and therefore predicting their changes often leads to a herculean task. Activities providing net return are influenced by the changing climate depending upon variable activities (Irland et al. 2001). Some activities such as fishing in cold-water stream, skiing in the snow and lake-based recreation may be severely affected as a consequence of the increasing temperature and climate change (Irland et al. 2001; Alig et al. 2004; Yadav et al. 2017).

In an Indian perspective almost half of the population is directly dependent upon fuelwood. It has been found that rural people are more dependent (65%) than urban people on fuelwood for cooking purposes (NSSO 2001). As per MoEF (2006) report, half of the fuelwood demand is being met up by natural forests, and the rest comes from farm forestry and extension forests. It has been found that there is sufficient amount of gap in demand and supply of forest resources which promotes unsustainable harvesting of woods (Khanduri and Mandal 2005; Aggarwal et al. 2009; Fig. 6).

As India is a land of domesticated animal, huge pressure is implied on pastureland also. This, therefore, causes destruction of grazing land by a huge amount of domesticated cattle which crosses the caring capacity (ICFRE 2001). Anthropogenic encroachment in the forest area also promotes unsustainability in the forest ecosystem (MoEF 2006). Various activities, i.e. grazing, trampling and lopping, significantly affect the regeneration potential of forest species and cause local biodiversity loss (Raj et al. 2018b) (Table 4). Considering the problems, SFM practices need to be implemented throughout the country in order to promote forest conservation on one hand and protect forests from various disturbances (natural or anthropogenic) on the other. Therefore, various practices such as integrated system of agricultural and forestry practices in the form of agroforestry, farm forestry and social forestry can be applied for solving the two-dimensional problem in the forestry sector (Jhariya et al. 2015). From a management perspective in India, it is reflected that the

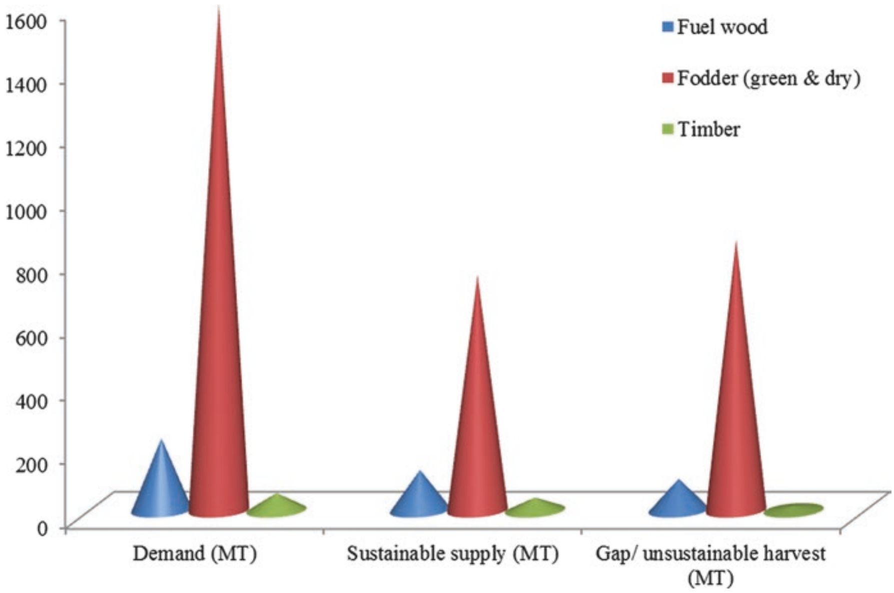

Fig. 6 Forest products demand-supply gap: Indian perspective. (Aggarwal et al. 2009)

government department has maximum contribution in forest management practices, and joint collaboration between government and local community stakeholders is much lesser than government institutions. The least management support was found from the private sector (Fig. 7, MoEF 2006). SFM jointly addresses the issues of forest and biodiversity conservation on one hand and livelihood security of the local community stakeholders on the other. Further SFM maintains the ecological health and process in forest ecosystem (Fig. 8).

9 Policies Towards Sustainable Management

Mitigation and adaptation to climate change through forestry application have always been correlated with policy issues. This includes an integrated approach which helps to serve the purpose of environmental conservation and protection. However an additional support in financial terms is required. The major problem associated with this is financial crisis in the forestry sector because there is no proper budget allocation. However, India is taking initiative in this respect as per the reports of 14th finance commission that proper budget allocation for individual state to increase the forest cover (GoI 2015). This approach also helps for ecological restoration of forest in different areas because almost half of the India's forest area belongs to open forest as well as anthropogenic pressure and improper regeneration become highly degraded (FSI 2013).

MoEF (2006) reported that up to 300 million human populations depend upon forest resources for their livelihood management. It is very surprising that forest

Table 4 Climate change-induced threatened tree species under red listed categories in the world (Newton and Oldfield 2008; Gonzalez-Espinosa et al. 2011)

Climate-induced red listed categories	Regions: Central Asian region	Ethiopia (African country)	Republic of Cuba	Meso-American dry forest	Montane tropical forests of Mexican region
Critically endangered (CR)	Twenty-five (25)	Forty-two (42)	Seventy-three (73)	One (1)	Eighty-three (83)
Endangered (E)	Twelve (12)	Thirty-five (35)	Twenty-three (23)	Seventeen (17)	Two hundred six (206)
Vulnerable (V)	Nine (9)	Twenty-eight (28)	Seventeen (17)	Twenty-four (24)	One hundred seventy-five (175)
Least concern (LC)	Twenty-five (25)	Nineteen (19)	Eight (8)	Four hundred fifty-seven (457)	Two hundred fifteen (215)
Near threatened (NT)	Eight (8)	Nine (9)	Two (2)	Thirty-nine (39)	Seventy-eight (78)
Data deficient (DD)	Eighteen (18)	Two (2)	Two (2)	Six (6)	Two (2)
Not evaluated (NE)	Not reported	Zero (0)	Not reported	Not reported	Zero (0)
Total	Ninety-seven (97)	One hundred thirty-five (135)	One hundred twenty-five (125)	Five hundred forty-four (544)	Seven hundred sixty-two (762)
Threatened percentage	Forty-seven (47%)	Seventy-eight (78%)	Ninety (90 %)	Eight (8%)	Sixty-one (61%)

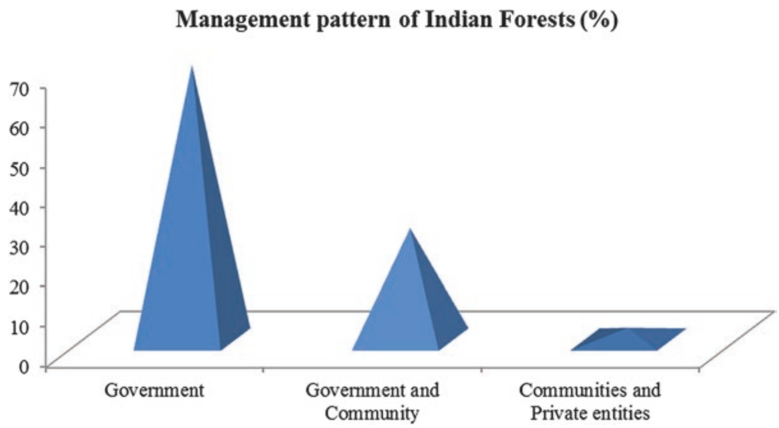

Fig. 7 Management pattern of Indian forests. (MoEF 2006)

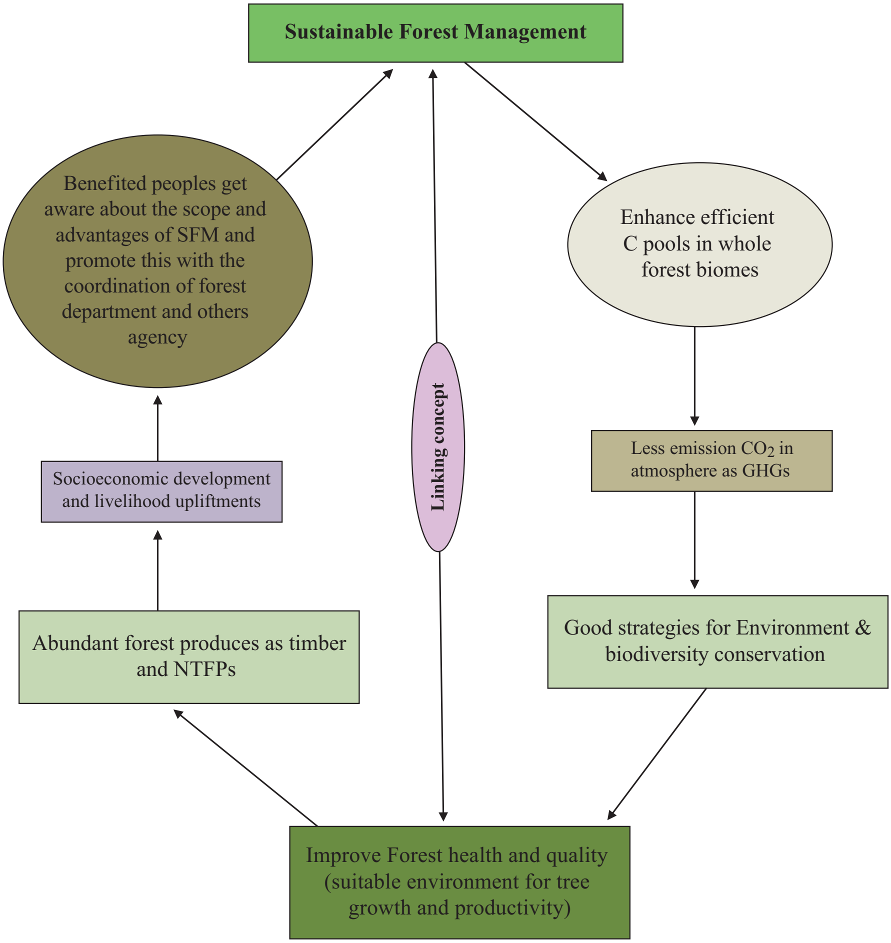

Fig. 8 Role of SFM in biodiversity conservation and livelihood upliftments. (FAO 2006, 2016; UN 2017; Pirlot et al. 2018; D'Aprile et al. 2015)

dweller and those who depend upon forest resource are still in search of security in terms of ownership of land and resource since India became independent. After the inception of Forest Rights Act 2006, people are eagerly waiting for their right over forests. Regarding implementation of this act, issues such as right recognition and site and individual selection are a big challenge (MoEF and MoTA 2010). However, the Indian government has brought amendment in 2012 to resolve the issues such as livelihood dependency and rights of the community people. As per the records of MoTA (2015), 1.56 million claims settlement regarding forest right encroaching up to 4% of area has been completed. In this connection, tribal states such as Chhattisgarh and other states such as Rajasthan and Orissa have revealed almost cent percent individual and 0.4% community rights, respectively.

For SFM, proper forest inventory along with information related to structure, composition of vegetation, sampling process and quantification methods acts as the principal source of forest information. This also frames the base of C stock and wood biomass stock and annual increment of forests. Competent forest inventories and information at the national level need to be upgraded through using advanced technologies such as remote sensing. Further C stock in wood products needs to be monitored in order to use forests as a tool for combating climate change. While thinking about SFM, good governance, suitable policy formulation and strategy development aiming towards adaptation and mitigation of climate change need to be built up both at the national and international level. One of the key issues includes interlinkage between forests and other sectors towards adaptation to climate change (Fig. 9).

During the British rule, forest was considered as an economic resource to provide raw material for mankind. As a consequence, at that time forest was simply a timber-yielding production system. But the scenario changed after independence through formulation of NFP (National Forest Policy) 1952, where the focus was given to the ecological integrity as well as fulfilling human needs. Afterwards, with the passage of time, a new forest policy was formulated in the year 1988 considering the ecological, economic and social dimensions of sustainable development. Therefore the urgent need for the implementation of sustainable policies is being established. In recent times a change in paradigm from consumeric forestry approach to sustainable forestry approach has taken place. However, sustained yield seems to be the principle objective on modern scientific basis which forms the central theme of organized forestry approach.

Strategies aiming towards SFM should address for development of technologies that promote lesser impact of climatic events, reduce risks of climate change and arrange the ecosystem to work as climate shocks. Ecosystem-oriented approaches include conservation and restoration of degraded forest land along with climate change adaptation (IUCN 2008). All these issues can be addressed under national policies that would raise social awareness in terms of recognizing values of forest ecosystem services (Vignola et al. 2009).

10 Future Prospectus of Forest and Climate Research and Development

Future exploration is still awaited towards identifying the possible vulnerable issues in terms of having negative impacts due to climate change. It is a big challenge to manage issues like pest infestation, disease outbreaks and genetic resource development along with maintaining forest ecological values. Integrated and interdisciplinary works need to be addressed in this field. Another essential mandate is that SFM should be brought under the banner of political framework for effective adaptive implementation of SFM policies (Fig. 10).

From a world perspective, the impacts of climate change are still under uncertainty in many areas of Asian subcontinents. Projections related to precipitation

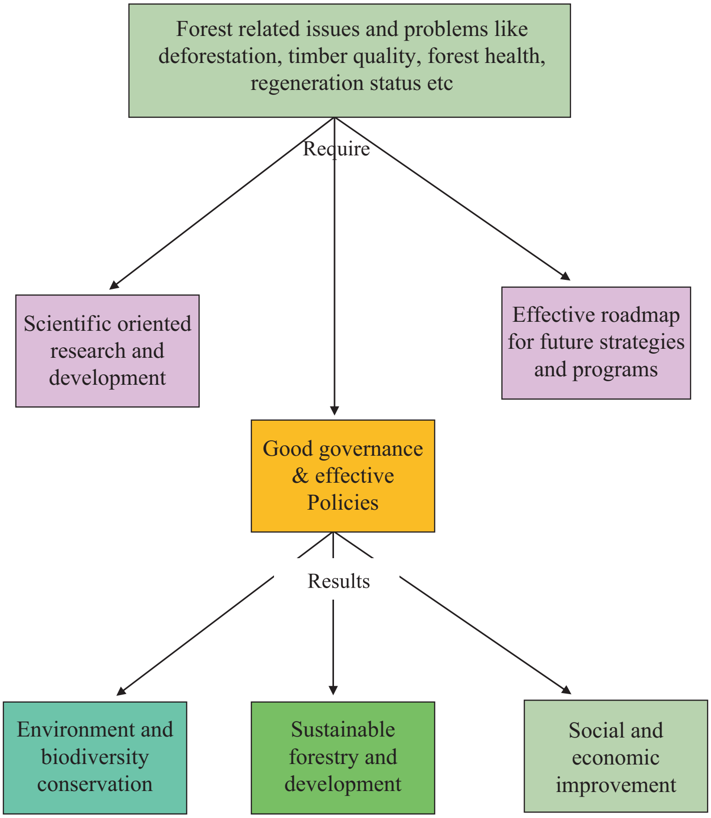

Fig. 9 Policies for SFM. (Pirlot et al. 2018)

pattern and supply of water are the most urgent need in order to sustain forest. The major limitation regarding information about climate change impacts in Asia is due to inadequate information about biodiversity (UNEP 2012). Very interestingly proper inventories of biodiversity at the national level are scarce resourced, and even in some cases, baseline information is inadequate. Further for tropical condition issues such as the influence of temperature for C fixation in tropical plants and thermal resilience, the impact of increase of ambient CO_2 level is a big knowledge gap (Zuidema et al. 2013).

Dynamics of the boreal biome depends upon various interactions between increase in temperature and ambient CO_2 level. Further natural events and insect infestation also may influence such dynamics (Zhang et al. 2011; Kumar et al. 2017). To have a detailed idea about interrelationship between climate change and forest dynamics, information related to species composition and biology along with modelling (ecological and environmental) would become very much essential (Meleshko and Semenov 2008). A wide lacuna in knowledge exists in the area of climate change predictability and associated impact over forests of different

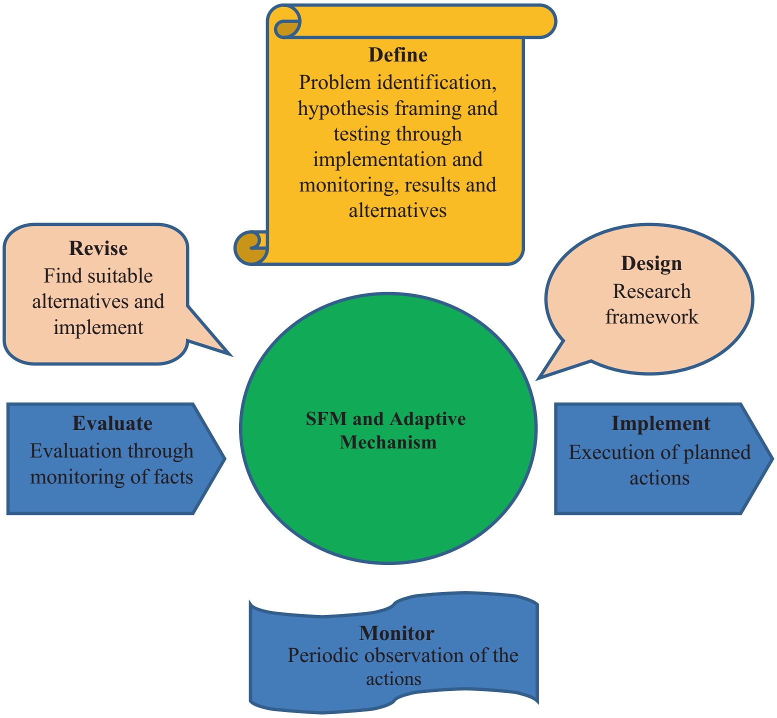

Fig. 10 The SFM and adaptive mechanism. (Murray and Marmorek 2004)

countries. Database in relation to elevated temperature needs to be procured for further improvement in the future trend of the changing climate which incorporate local issues such as region-specific conditions, nature of forest produce, genetic resource base and various values of forests.

SFM includes ecosystem-oriented approach which should incorporate programmes related to forests at the national level, development of model forests and various certification systems. SFM is such an approach which includes integration at the cross sectoral and inter-sectoral level which involves people, forests, habitat and biodiversity. Climate change mitigation in forestry sectors is very much economy oriented due to livelihood generation for rural people. Forest ecosystem plays a multidimensional role through GHG emission reduction, C sequestration and reducing the risk on people and ecosystem towards climate change. Throughout the world, the major aim should be to control the loss of forests. In this context, suitable management strategies for forest conservation would be highly fruitful. Scientific exploration and proper research road map need to be designed in these areas for utilizing forests towards mitigating climate change.

From an Indian perspective, one has to face severe challenges in terms of policy implementation in the forestry sector. Therefore, policies should be aimed towards controlling of forest depletion, reducing impact of climate change on forests and providing livelihood sustainability throughout the country. It has been observed that the gap between demand and supply of forest products is imposing negative consequences in the forestry sector. Policies can be formulated on time span basis (short-, mid- and long-term) depending upon the prevailing scenario. Research investigation towards the changing climate and degradation of forests may incorporate the development of vulnerability index for forests which includes clear databases related to density of forests and biodiversity along with shifting of vegetation type in the near future. Such studies revealed that the northern and central part of Western Ghats hills along with the upper part of the Himalayas would be highly vulnerable in this context and vegetation of the northeastern region would act as ecologically resilient (Chaturvedi et al. 2010).

From a short-term perspective, collaboration between education institutes, forest department and private organization is very much essential to produce sustainable resource base. In this connection, India has already progressed through its 5-year plan to establish nurseries in selected forest zone. NFP of 1952 and 1988 has emphasized to increase the forest cover, but mere 5.71 million hectare areas reflected an increment of forest cover for the last 28 years (FSI 2013). As per forest policy, the target of increasing forest cover up to 33% is merely theoretical under the pressure of modernize society, and therefore, the government has modified the aim by increasing up to 5 million hectare under the 5-year plan (Planning Commission 2013). Of this 5 million hectare, 2 million hectare would be in the form of extension forestry or afforestation scheme and 3 million hectare in the form of reforestation. The energy sector has a big role to play in this connection towards rural community. The expansion of liquid petroleum gas distribution in the rural livelihood along with the promotion of using improved chullahs may bring the benefit by saving up to 400 kg fuelwood per annum.

The World Bank report (2006) revealed a higher economic gain in terms of ecotourism operation in various joint forest management areas. Ecotourism can be judiciously promoted through involvement of private sector and local community people which would work in the direction of capacity building. Identification of community rights through proper legal procedure should be promoted, and subsequently illegally occupied areas should be cleared. Bottlenecks of the forestry sectors should be properly taken care for promoting SFM. For instance monitoring over government revenue earning through forests produce, strict implementation of laws, allotment of credibility to the poor people along with proper valuations are some of the major issues. Local people should be trained on these aspects to make them participate in the value addition process. Addressing climate change in the forestry sectors needs awareness creation among the staff of forest department along with local people to make climate adaptation successful. In this process arresting forest fire and fragmentation of forests may be implemented.

From a midterm perspective, some areas can be improved through mixed plantation with subsequent natural regeneration of vegetation. Additional area can be procured through plantation in the common and private lands under various schemes such as agroforestry and social forestry. Restriction over felling and transportation of agroforestry species should be mediated through legal means and promote local species plantation on private lands. Strengthening and upgradation of knowledge base in terms of advanced agricultural practices, animal husbandry and SFM should be inculcated among the local stakeholders for livelihood improvement. The focus is on NTFP collection and marketing under the joint collaboration between community stakeholders and private organization. Cooperative formation in this context for proper evaluation of NTFPs is a very fruitful step. Gram panchayat should be actively involved in this matter, and green funds should be raised to promote green volunteers to work for natural resource management. Scientific information on climate change impact on structure and ecological services of forests should be integrated with SFM.

From long-term perspectives, forest cover can be increased through various plantation schemes and by natural regeneration process. Promoting the use of alternate energy sources and liquid petroleum gas sources may help to reduce the pressure of forest dependency. The concept of joint forest management should be modified in the form of community forest management under which gram panchayat will play the key role and forest department would monitor the efficient implementation of different policies. Simultaneously forest enterprises at the small level should also be promoted which may contribute significantly towards livelihood improvement. Findings of the research programmes from climate change adaptation perspectives should be integrated with forest management and working plan. Overall climate change adaptation should include information related to the influence of changing climate on forests and changing pattern of vegetation along with SFM.

11 Conclusion

The most interrelated issue in modern context is the changing climate along with managing sustainability of natural resources. Vegetation plays a diverse role for the survival of human being and biodiversity. Due to climate change, forests are now becoming under severe threats of depletion, and as a consequence, human civilization would be starving for the services of forests. Forests provide resources in the form of livelihood under changing climate which would support the sovereignty of forest dwellers. As the whole world is changing under the impact of climate change, therefore multiple uses of forests would be the need of the hour. For effective management community participation, industry-institute-local stakeholders-government partnership and capacity-building policies need formulation towards achieving sustainability. From a changing climate perspective, mitigation with adaptation is required to run simultaneously by adopting SFM strategies. SFM strategies include practising processes that promote more C sequestration, and more ecosystem resilience. Simultaneously sustainable harvesting and lesser resource dependency generation through alternate practices such as agroforestry, farm forestry, social forestry, extension forestry and NTFP production and marketing would act as suitable SFM. However there are some key challenges that may hinder the effective implementation of SFM strategies. Small landholding, lack of technical expertise, less efficient marketing mechanism and lack of funding are the principal obstacles that hinder effective management of forests aiming towards mitigating climate change. Due to severity of climate change, one has to opt for SFM practices due to their multidimensional role. SFM practices promote biodiversity conservation, provide livelihood for local community stakeholders, maintain ecological integrity, promote forest conservation and restoration and therefore support human civilization for their prosperity. Policy formulation would be very important from a climate change perspective in the form of risk management to be incorporated under the planning of SFM.

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