Climate Change Management

Walter Leal Filho · Jelena Barbir
Richard Preziosi *Editors*

Handbook of Climate Change and Biodiversity

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Climate Change Management

Series editor

Walter Leal Filho, Faculty of Life Sciences, Research and Transfer Centre "Sustainable Development and Climate Change Management", Hamburg University of Applied Sciences, Hamburg, Germany

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Richard Preziosi
Editors

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Editors
Walter Leal Filho
Faculty of Life Sciences, Research and Transfer Centre “Sustainable Development and Climate Change Management”
Hamburg University of Applied Sciences
Hamburg, Germany

Jelena Barbir
International Climate Change Information and Research Programme
Hamburg, Germany

Richard Preziosi
School of Science and the Environment
Manchester Metropolitan University
Manchester, UK

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Preface

Climate change as a whole, and global warming in particular, are known to have a negative impact on biodiversity in three main ways. Firstly, increases in temperatures are known to be detrimental to a number of organisms, especially those in sensitive habitats such as coral reefs and rainforests. Secondly, the pressures posed by a changing climate may lead to sets of responses in areas as varied as phenology, range and physiology of living organisms, often leading to changes in life cycles (especially but not only in reproduction), losses in productivity, or even death. On occasions, the survival of some very sensitive species (e.g. corals) may be endangered. Thirdly, the impacts of climate change to biodiversity are estimated to be felt in the short term in respect of some species and ecosystems, but also in the medium and long term in many biomes. Indeed, if left unattended, some of these impacts may be irreversible.

Many individual governments, NGOs, financial institutions and international donors are currently spending billions of dollars in projects around climate change and biodiversity, but with little coordination. Quite often, the emphasis is on adaptation efforts, with little emphasis on the connections between physio-ecological changes and the life cycles and metabolisms of fauna and flora, or the influence of poor governance on biodiversity. There is therefore a perceived need to not only better understand the impacts of climate change on biodiversity, but to also identify, test and implement measures aimed at managing the many risks climate change poses to fauna, flora and micro organisms. In particular, the question as to how better restore and protect ecosystems from the impact of climate change, also has to be urgently addressed.

This book has been produced to address this need. Papers here compiled look at matters related to the use of an ecosystem-based approach to increase local adaptation capacity, consider the significance of protected areas network in preserving biodiversity in a changing northern European climate, and the impact of climate change on specific species, and wild terrestrial animals. It also presents a variety of case studies such as the Yellowstone to Yukon Conservation Initiative, the effects of climate change on the biodiversity of Aleppo pine forest of Senalba (Algeria), climate change and biodiversity response in the Niger delta region of Nigeria, and the impact of forest fires on the biodiversity and the soil characteristics of tropical peatlands in Indonesia. Moreover the book also entails contributions on how to promote the climate agenda and biodiversity conservation at the local level.

It is a truly interdisciplinary publication, and we hope it will be useful to scholars, social movements, practitioners and members of governmental agencies, undertaking research and/or executing projects on climate change and biodiversity across the world.

Hamburg, Germany Walter Leal Filho
Hamburg, Germany Jelena Barbir
Manchester, UK Richard Preziosi
Winter 2018/2019

Contents

Water Management and Climate Change in the Focus of International Master Programs in Latin America and the Carribian

Frido Reinstorf, Petra Schneider, Raymundo Rodriguez Tejeda, Leslie Santos Roque, Henrietta Hampel and Raul F. Vazquez

Abstract Water is regional priority around the world but synthesis of water resource management aspects from local-to-global scales is currently not included in not currently included higher education curriculua of Latin American and the Caribbean (LAC) universities. This leaves local populations vulnerable to future shifts in climate at global scales and changes in land usage at regional scales. To close this gap, the project "WATERMAS—Water Management and Climate Change in the Focus of International Master Programs", is financed by the European Union. The project will develop and establish a new standard of higher educational and scientific knowledge exchange between Europe and Latin America as well as the Caribbean. This will be done leveraging existing Master's courses/programs of Water Management at the various partner universities in Latin America (LA), respectively in Cuba and in Ecuador. The scope of the project is to enable the development of strategies

F. Reinstorf (✉) · P. Schneider
University of Applied Sciences Magdeburg-Stendal, Breitscheidstraße 2, 39114 Magdeburg, Germany
e-mail: frido.reinstorf@hs-magdeburg.de

P. Schneider
e-mail: petra.schneider@hs-magdeburg.de

R. R. Tejeda · L. S. Roque
University of Holguin, Avenida XX Aniversario 4, 80100 Holguin, Cuba
e-mail: rtejeda@uho.edu.cu

L. S. Roque
e-mail: lesliesantosroque95@gmail.com

H. Hampel · R. F. Vazquez
University of Cuenca, 12 of April Avenue, 01.01 Cuenca, Ecuador
e-mail: henni.hampel@ucuenca.edu.ec

R. F. Vazquez
e-mail: raul.vazquezz@ucuenca.edu.ec

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for the adaptation of local water management facilities and the biodiversity with regard to future challenges in the partner countries targeting a Society-Education-Research Nexus. The project addresses sustainability under the Teaching-Research-Practice Nexus, particularly the UN Sustainability Development Goals (SDG) 4 (Quality Education), 6 (Clean Water and Sanitation), 11 (Sustainable Cities and Communities), and 13 (Climate Action). Besides the water management aspects the biodiversity guaranties the functionality of eco system services, which plays an important role by considering the value of the nature for the mankind.

Introduction

Water is fundamental for the economy and quality of life in every country of the world; however, this renewable resource is increasingly threatened by human activities (i.e. pollution, overexploitation). Further, due to this human influence on earth processes, the global climate is changing, affecting the availability and frequency of natural rainfall. In Latin America (LA) long term prediction foresees more or less the same amount of rain in the future but its distribution will change causing longer periods of drought and increased intensity and frequency of rainfall resulting in severe flooding and devastating consequences (IPCC-AR5 2014). Moreover, the hydrological cycle is influenced by complex meteorological phenomena such as “El Niño” and “La Niña”, which produce extensive damage with regard to the local-to-global economy and can bring also significant human losses in the affected countries. In Europe, especially in the southern countries like Spain and Italy, water crisis is more and more severe each summer, e.g. summer water crisis in 2008 when water needed to be imported to Spain. Only the retention of water in reservoirs, and even the re-use of heavily salty wells, e.g. in Cataluña, can fairly satisfy the water demand (Maracchi et al. 2005).

Such climate change is exacerbated by coupled impacts of land use changes associated with, for instance, agricultural frontier expansion and related water use to feed growing populations and satisfy other urban needs. Moreover, in LA, especially in Ecuador, in the last few years, aiming at securing and diversifying energy sources, several hydroelectric power stations started to function and many more are under construction, e.g. Paute Dam and Mazar Dam (WEC 2017). The lack of control on environmental flow results in strong impact on the river system functioning and its capacity of recovery. Contamination due to the lack of control of industrial and agricultural activities and lack of water treatment plants prior river disposal (e.g. only three cities in Ecuador have adequate sewage treatment systems, in Cuba there are no norms for the design of waste water treatment plans) further aggravates the water related problems. In addition, as the result of the last few years of strong economic development, water consumption increased dramatically reaching in average 200 L per day in LA cities. Due to the above mentioned issues all countries globally will have to face water related problems in the future. But these problems will be especially severe in LA where countries are highly vulnerable due to the lack of mitigation and adaptation strategies (WWDR 2015). In the most affected regions the economic development growth will be hindered promoting further growth of poverty and desperation among inhabitants, with potential consequences on the rise of criminality and other social issues.

In the European Union (EU), the Water Framework Directive (WFD 2000) aims to achieve good qualitative and quantitative status of all water bodies. Also, the new status of ecosystems, which considers not only the conservation of biodiversity but also the new aspect of improving the ability of ecosystems to deliver eco system services, plays an important role in the strategy of the EU (COM 2011, 244). However, in LA, where the proposed project will be executed, the focus is different. For instance, in Ecuador exists the "Law of the use and exploitation of water resources" but this does not mention at all anything on the protection of water bodies but only guarantees "good" and enough water for the population. Strikingly, despite water's recognition as a very important regional priority, water conservation, protection, environmental flow definition, and relation to good ecosystem functioning are very rarely considered in legal regulations and decision-making. Even more significant as we look to future generations of managers, these integral aspects of water resources are not included in the vast majority of curricula development for higher education across LA. Further, these curricula need to implement up-to-date scientific and technological knowledge, aiming at increasing the local skills and expertise of young students and professionals as multiplier on key water resources (WR) aspects such as optimisation of use, conservation and management; promoting at the same time, common values, social integration, intercultural understanding and language/communication skills, as a way of overcoming current educational deficiencies that constrain professionals to a narrow working environment. This is what the WATERMAS project targets.

The Project: "WATERMAS—Water Management and Climate Change in the Focus of International Master Programs"

General Aspects

WATERMAS is a project financed by the European Union under the ERASMUS + program in the period 2017–2019. Partners are the University of Applied Sciences Magdeburg-Stendal (UAM, Germany), the Universities of Holguin (UHo, Cuba), Gent (UG, Belgium), Cuenca (UC, Ecuador), Stockholm (SU, Sweden) and the Polytechnical School of Litoral Guayaquil (ESPOL, Ecuador). As such, WATERMAS focuses in the regional priority for boosting academic curricula in the field of water resources (WR) with the innovative goal of including perspectives of conservation and protection of WR leveraging management aspects from local-to-global scales especially in the view of climate change.

Hence, the participating institutions have very high level teaching and/or research expertise in a broad range of WR issues. Nevertheless, particularly the LA institutions have the necessity of connecting to more modern knowledge, especially on water conservation and management issues, as well as, language skills. In this respect, the exchange of students and teachers targeting an ability to share knowledge and transfer research among universities in the LA and EU contexts will further provide support to current and future decision makers and civil society in general. This will guarantee not only the successful execution of the project objectives but also the future sustainability of its outcomes.

The general approach is to include several important and unique aspects, such as (1) the transference of the EU view on WR management on the basis of the Water Framework Directive (WFD) application; (2) the wide range of WR related expertise of the partners (e.g. hydrology, hydrogeology, hydraulics, water quality, water management, river/lake monitoring/restoration, climate change, landscape/aquatic ecology, ecosystem functioning, environmental flow) will provide a complete overview on water issues in the view of climate change; (3) the long teaching/research trajectory of the participants will ensure effective knowledge transference; and (4) different WRes problems from the participating countries (e.g. Belgium: severe reduction of intertidal areas of rivers and related flood events; Germany: pollution vs. water use from transboundary rivers; Ecuador: lack of proper legislation for environmental flow, severely increased water consumption) will be analysed and presented as case studies, profiting from the significant expertise of the partners.

Currently, there exists already a student exchange program between University of Applied Sciences Magdeburg-Stendal (UAM, Germany) and University of Holguin (UHo, Cuba), through which lecturers/scientists from both universities worked together to create a jointly taught course given at the UHo and initiated common research on WR applied on Cuba. Further, the universities of Gent (UG, Belgium), Cuenca (UC, Ecuador) and the Polytechnical School of Litoral in Guayaquil (ESPOL, Ecuador) have a long term collaboration (20 years) through the VLIR (Flemish Council of Universities) program, which promoted mobility actions, technology transference and development of research projects and an interuniversity M.Sc. program in WR (while a related Ph.D. program is currently being planned). Hence, the integration of these well stablished and fruitful networks gave birth to the current proposal that in addition involves the collaboration of the University of Stockholm (SU) due to its relevant complementary experience on WR and expertise on well-aligned curriculum development connecting research and application.

Climate Change in Latin America with Focus on Cuba and Ecudador

The climate of the Central and South American continent is extraordinarily complex. On the one hand, the long continent reaches from the tropics of the northern to the tundra climate of the southern hemisphere. On the other hand, the Andes and the

Fig. 1 Location of the countries in the focus of WATERMAS

mountains of Central America cause great differences on the west and east sides of the continent. Cuba and Ecuador, the countries in the focus of the project, are located in the Latin American and Carribbean (LAC) LAC region, see Fig. 1.

The LAC countries are considered particularly vulnerable to climate change, on the one hand by a possible increase in hurricane activity and on the other hand by the rise in sea levels (IPCC 2007, 2013; UNEP 2010). While sea-level rise is more a global phenomenon, but particularly prone to Caribbean islands, the frequency and intensity of Caribbean hurricanes are heavily controlled by the climate of the tropical Atlantic and the Caribbean itself (Pielke et al. 2013). The Caribbean climate is initially determined by the subtropical high above the Atlantic. It lies far to the south in winter and brings drought to the region. In the summer, it shifts to the north and makes room for east winds, causing rain from May to November. From June to November, when sea surface temperatures are above 26.5 °C, these easterly winds may develop into tropical storms and hurricanes, bringing the bulk of precipitation. The whole system is under the influence of the El Niño Phenomenon in the South Pacific and the North Atlantic Oscillation (NAO). El Niño years provide more dryness and less hurricane activity across the Caribbean, La Niña years for wetter conditions. A positive NAO phase intensifies the subtropical high pressure area and thus also causes a reduction in rainfall (IPCC 2007, 2013).

The devastating effects of climate change are already evident in LA today. Expected impacts of climate change in 2050 can be seen in Fig. 2. Regions with increased vulnerability to weather extremes like storms, droughts and floods changes in biodiversity as well as the risk of desertification can be located. Crop failure, water

Fig. 2 Expected impacts of climate change in 2050 in Latin America (Landa et al. 2010)

scarcity and landslides are some of the consequences as well as a higher risk of diseases, impacts on agriculture and fisheries. This especially affects poorer people in the countryside. For many small farmers, for example, climate change is already an existential threat today. Overall, it leads in LAC societies to ever greater ecological and social upheavals. Added to this is the continued exploitation of natural resources for more and more economic growth, which accepts the social and environmental damage that goes along with it.

By the end of the 21st century, the LAC region is expected to see a temperature increase of about 2–3 °C, slightly less than the global average, which has to do with the dominance of the sea over land (IPCC 2007, 2013). Not less important than the air are the water temperatures, because they determine the evaporation and the precipitation. Till 2050, the sea surface temperature is expected to increase by 1 °C. This should result in higher precipitation, as predicted by a model calculation for August to

October (Angeles et al. 2007). However, the IPCC assumes drier conditions in Central America and the Caribbean at the end of the 21st century. The reason is that in the East Pacific, more El-Niño-like conditions are expected in the future, and an increase in the North Atlantic Oscillation (NAO). Both changes lead to less precipitation in the Caribbean (IPCC 2007). An exception is only the northern Caribbean in the winter months (IPCC 2013). A warming of the eastern tropical Pacific, from which an El Niño develops, intensifies the subtropical jet stream, which in turn amplifies vertical heavy winds across the Caribbean that obstruct the convection of humid air. A positive NAO phase increases the Atlantic subtropics high and the trade winds, causing the Caribbean Sea surface temperatures to cool (Angeles et al. 2007).

In addition, there are many problems and deficiencies that contribute to the vulnerability of the LA countries in terms of climate change (Leal Filho and Mannke 2014), as there are:

- poor or non-existing climate change governance systems,
- limited awareness on the causes and consequences of climate change,
- endemic poverty,
- limited access to capital and global markets,
- continuous ecosystem degradation,
- complex disasters and conflicts,
- unplanned urbanization,
- limited capacity (personal and institutional) to address the problem and its many ramifications.

Conflicts due to climate change and environmental degradation, resource exploitation and scarcity of resources are exacerbated by the fact that they are directly linked to the distribution problem—that is, the question of how benefits and risks are socially distributed. On the one hand, the LA example shows the connection of environmental and climate problems with social and economic issues; on the other, the global dimension of climate change and environmental conflicts becomes clear: the gap between the main causes of climate change and beneficiaries of the economic system in the Global North on the one hand and, on the other hand, people who are marginalized are continuing to open up, partly because others can protect themselves against the consequences of climate change. But looking at LA not only highlights the implications and inequalities surrounding the global climate change problem, it also opens up hopeful alternatives: In some LA countries, people are pioneering ways of reconciling human development, social justice and environmental sustainability.

Methodology

To increase the local expertise for optimising the management of WR, in LAC countries academic curricula needs to incorporate the perspective of protection and conservation of WR and their advantages, especially in the view of climate change, and up-to-date scientific and technological knowledge. EU partners have a very diverse research/teaching/technological/management expertise on these WR issues, which will help solving local WR problems by increasing local expertise and, in the mid-term, could be incorporated into local/regional decision making systems, which in turn would represent a huge contribution to regional WR management. Further, collaboration between EU and LAC countries will generate joint knowledge on WR issues, which will allow the establishment of thematic networks that will be sustainable through common research projects, scientific publications and mobility actions involving both students and researchers.

The main research questions of the project are:

- Which are the main contents to be included in curricula for teaching water management and climate change in the focus of international master programs for the LAC region?
- How can a continuing education program for teachers contribute to curriculum development in the sense of higher education for climate adaptation and sustainable development?
- Which competencies are developed individually?
- How can water management and climate change be integrated into the teaching routines in a transdisciplinary way? Which new and innovative pedagogical approaches are feasible to be implemented under LAC conditions?
- What contributions are there for the development of the university?
- How does the program contribute to the dissemination of climate mitigation and adaptation as a cross-cutting issue in the university and outside?

The general approach of the project to provide answers to the above questions is the knowledge value chain according to Weggeman (1996), which provides a structured approach on the base of knowledge management routines. The knowledge value chain represents a transfer of a technique to teaching, which has proven itself in practice. The knowledge value chain is starting from MVOS (mission—vision—objectives—strategy), followed by Developing knowledge—sharing knowledge—Applying knowledge—Evaluating knowledge, a process, which is under cyclical repetition (Weggeman 2000), as analogue to the Deming cycle (Deming 1982). The methodology in the WATERMAS project is based on the creation of a common knowledge base by cooperation, exchange and dissemination among the network participants to promote curriculum development with the following key activities:

- Identification of the main topics of the curricula regarding water resources conservation and management both from a regional and global perspective
- Collection of relevant information material (national standards, publications regarding regional and global water management aspects and land use impacts, examples of existing curricula, etc.) among the partners with subsequent assessment, summarization and distribution as presentations at workshops
- Assessing local and global scientific information relating to the project aims. Discussion of the information, producing outlines of articles and decisions regarding the implementation within the virtual data base

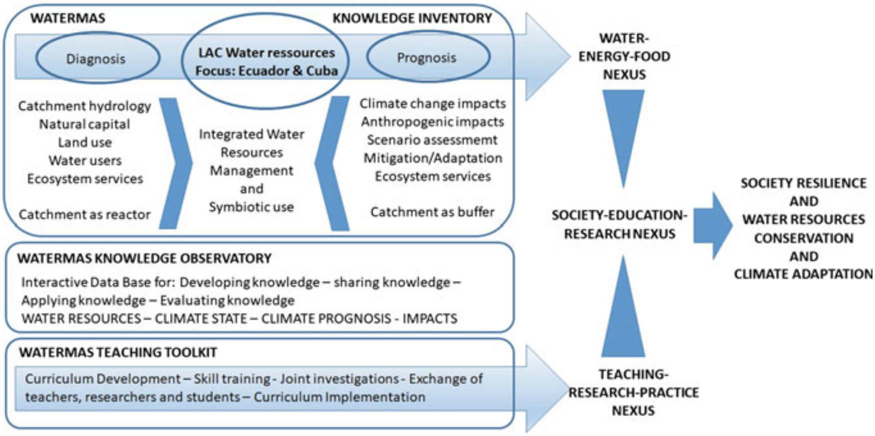

Fig. 3 Methodology for the implementation of the WATERMAS project

- Identification of the main local impacts of land use and climate change on the water resources
- Participation in joint investigations targeting the interests of the regions, e.g. erosion in landscape and riverbeds, hydrological extreme events, standard hydrological methods, high flood protection, biodiversity, European regulations and rules (water framework directive, groundwater directive etc.), dam construction, damage of dams and spillways, coast protection, International Water Management, which will be implemented through the exchange of M.Sc. students and project participants between universities.
- Exchange of teachers, researchers and students across different levels of higher education among the participating universities.
- Develop skills in technical (e.g. water sampling, water treatment and water supply technologies, numerical process modelling, using of Geographical Information Systems) and methodological (e.g. teaching methods, e-learning) training within the group of network participants and other involved persons in the different countries in order to strengthen their skills and abilities (i.e. How can we connect education and research directly for the benefit of not only students but also researchers?)
- Development of a list of relating aspects of conservation and management of water resources under European standards in consideration of local and regional characteristics to include them within the new curriculum.

The methodology for the implementation of the WATERMAS project will be structured in the following way (Fig. 3):

The three main basic working fields in WATERMAS, which are inventory, observatory and teaching lead to the three main impact nexus' for water-energy-food, teaching-research-practice and society-education-research and furthermore to the three social results society resilience, water resources conservation and climate adaptation.

Teaching and Learning Contents to Be Addressed

Fundamentals and Definitions

The exacerbating impacts resulting on the changes of the climate system on the water resources systems and the complexity based on interacting systems are issues that becoming increasingly importances. Damages and alterations in the atmosphere, global warming, impacts on the oceans, the cryosphere, changes in sea level, as well as differences in carbon concentrations and other biogeochemical magnitudes are inescapable. These affect the normal balance of ecosystems and force humans to seek alternatives to adapt to new conditions and find immediate solutions. In this context the understanding of the impacts requires the consideration of the interrelations between water resources—water scarcity—water risk—water stress—water security as well as water resources—water use—waste water discharge—waste water treatment. These fundamental interrelations within the Water Resource Management (WRM) are necessary to implement in learning and teaching contents, including the interrelations between WRM aspects and other natural resources like ecosystems.

Displaying the Scales of the Hydrological Cycle and the Impacts of Climate Change in the Curriculum

Scope of this part of the curriculum will be to get knowledge of the fundamentals of hydrology, as well as to get knowledge of hydrological processes and methods for the estimation of hydrological variables, which are relevant for the dimensioning of hydraulic structures and for the use of water resources on all levels and scales. The classification of the spatial scales relevant for hydrology ranges from "micro" (up to about 1 km^2) via "meso" (up to 1000 km^2) to "macro" (from 10,000 km^2). To show how the different scales of the hydrological cycle and the impacts of climate change can be considered in curricula an understanding of the processes and known facts at the different scales is required. For that, a differentiation into the global, regional, and local scales is needed. Using the concrete examples of Cuba and Ecuador, it will be demonstrated how this content can be displayed in a curriculum.

Dimensions of WR Management to Be Considered in the Curriculum

Water resources are sources of water that are potentially useful for uses like agricultural, industrial, household, recreational and environmental activities. Water availability, including the security of water supply and sanitation, is essential to achieving the United Nations Sustainable Development Goals (SDG; United Nations 2015). Water availability, which UNESCO refers to as available fresh water resources (UN-Water 2006), indicates the amount of fresh water that is available to one person per year. According to Gerlak and Mukhtarov (2015), water security has emerged as a new discourse in water governance challenging the more traditional dominant discourse of Integrated Water Resources Management (IWRM) in the past decade. The definition of IWRM that is most widely accepted and of relevance today was given by the Technical Committee (TEC, former Technical Advisory Committee, TAC), of the Global Water Partnership (GWP). It states that IWRM is "*A process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*" (GWP 2000).

IWRM is based on a management approach for balancing water demand and availability under a spatial planning approach, practically combining water management and water protection at catchment level (Grigg 2008). The formalised framework of IWRM was developed from the Dublin Principles that were ratified during the 1992 International Conference on Water and the Environment, through the following four guiding principles:

- Principle 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment
- Principle 2: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels
- Principle 3: Women play a central part in the provision, management and safeguarding of water
- Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good.

The Human Right to Water and Sanitation (HRWS) was recognised by the United Nations (UN) General Assembly on 28 July 2010 (UNEP 2010). A revised UN resolution in 2015 highlighted that the two rights were separate but equal (United Nations 2015). Through its focus on water, IWRM often neglects the needs of users from agriculture and/or energy services. To consider a more holistic approach, the Water-Energy-Food Security Nexus (WEF) has been proposed, linking the decision-making processes of the competitive users and balancing the "trade-offs" between them (Hoff 2011).

In the last decades, the awareness has grown that water is a scarce resource which needs to be managed also under the principles of environmental economics, particularly the water value chain, which takes the aspect of water being food into account. The "Water Footprint" (WF) is an indicator that shows the direct and indirect water consumption of a consumer or a producer (Hoekstra and Chapagain 2008). In contrast to direct water consumption, the WF also includes indirectly used water. The amount of water hidden in products is often referred to as "Virtual Water". The WF describes the total amount of water that nations, businesses or consumers consume.

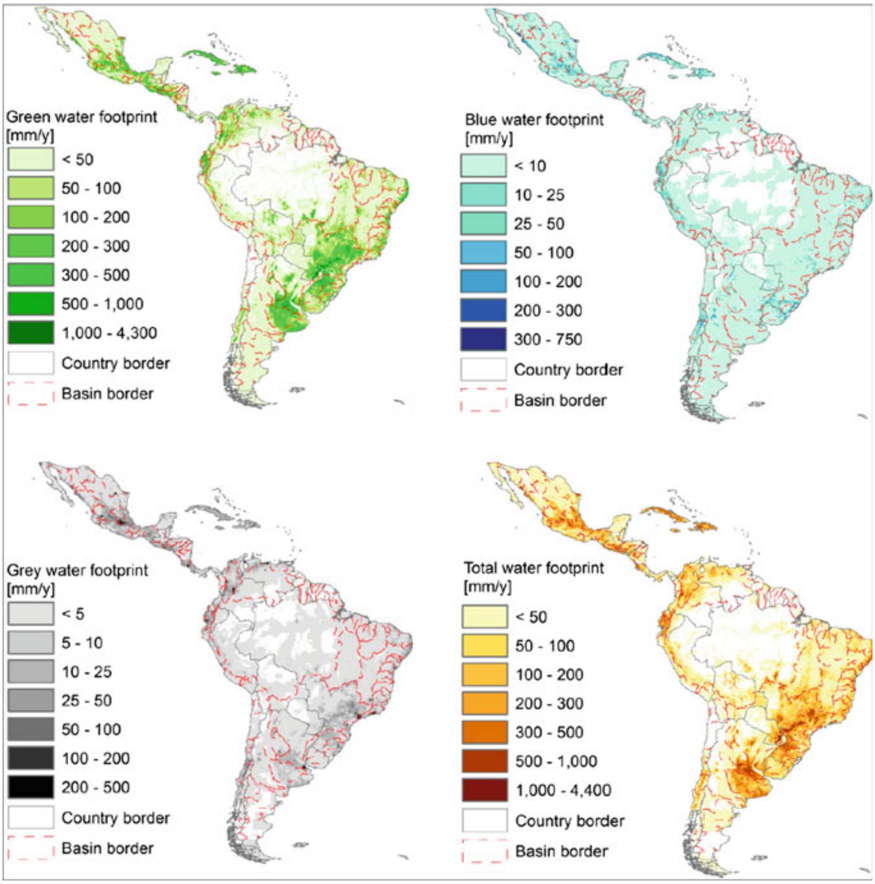

Fig. 4 The green, blue, grey and total water footprints in the LAC region (1996–2005) (Mekonnen and Hoekstra 2011)

The special feature of the concept is that it combines the amount of water that is used, evaporated and/or polluted for production, with information on both the consuming and the producing region of the product. Dividing the used water into categories is helpful for a later assessment of the WF. "Green water" is the naturally occurring soil and rainwater, which is absorbed and evaporated by plants. It is relevant to agricultural products. "Blue water" is ground or surface water that is used to make a product and is no longer returned to a body of water. In agriculture, it is the water for watering the plants. "Grey water" is the amount of water that is polluted during the manufacturing process. Figure 4 shows the green (GWF), blue (BWF), grey (YWF) and total water footprints (TWF) in the LAC region according to Mekonnen and Hoekstra (2011).

According to Mekonnen and Hoekstra (2011), the total WF of production in the LAC region in the period 1996–2005 was 1162 billion m^3/y (87% GWF, 5% BWF, 8%

YWF) (Mekonnen and Hoekstra 2011). About 21% of the WF within LAC is related to production for export. The gross virtual water export of the LAC region to the rest of the world was 277 billion m^3/y (Mekonnen et al. 2015). The LAC average WF of consumption was about 1769 m^3/y per capita. In LA does exist the Latin American Water Tribunal (Tribunal Latinoamericano del Agua, TLA), which is an autonomous, independent and international environmental justice organization created to help solve water related conflicts in LA and to support water management (Weaver 2011). The TLA work is based on the principles that the balanced coexistence with nature, respect for human dignity, and solidarity among peoples are are required for the preservation of the region's water systems. The TLA is committed to preserving the water commons for future generations and to guaranteeing access to water as a human right. Its legitimacy derives from the moral nature of its resolutions and the juridical fundamentals they are based on.

Climate Change—The Role of Biodiversity and Ecosystem Services

Biodiversity plays a significant role in the frame of the climate change mitigation strategy development and refers to the variability of living organisms and their ecological complexes. It includes (a) the diversity of ecosystems or communities, habitats and landscapes, (b) the biological diversity and (c) the genetic diversity within the different species. Various forms of the use of the natural capital, including biodiversity, have been grouped together under the term ecosystem services, without paying particular attention to the idea of nature conservation yet (Schröter 2017).

Ecosystem services (ES) are services produced by ecosystems through the function of the compartiments of the respective ecosystem, that provide essential benefits to human (Millennium Ecosystem Assessment 2005). The Millennium Ecosystem Assessment (2005) derived provisioning, regulating, cultural, and supporting services. Biodiversity is the prerequisite for a healthy and natural development of all living individuals and ecosystems. ES include e.g. purification of drinking water and air, climate regulation, pest and disease control, pollination and other mechanism of supporting food production, medicinal resources, flood regulation and the recreational value. ES are also provided by restored ecosystems, particularly forests under natural succession like secondary forests. According to a study of Lourens Poorter of Wageningen University in the Netherlands (Poorter 2016), secondary forests, unlike primeval forests, allow large amounts of water to circulate and renew soil fertility. Besides, they grow very fast. Covering 28% of LA's total land area, all industrial processes that emit CO_2 could be offset. Having in view the strong interrelation between WR and ES, the role of biodiversity and ES for the mitigation of climate change will be particularly outlined in the curriculum. Figure 5 shows the predicted value (per hectare) of ecosystem services and loss in ecosystem services due to habitat loss, 2000–2010 (Mekonnen et al. 2015).

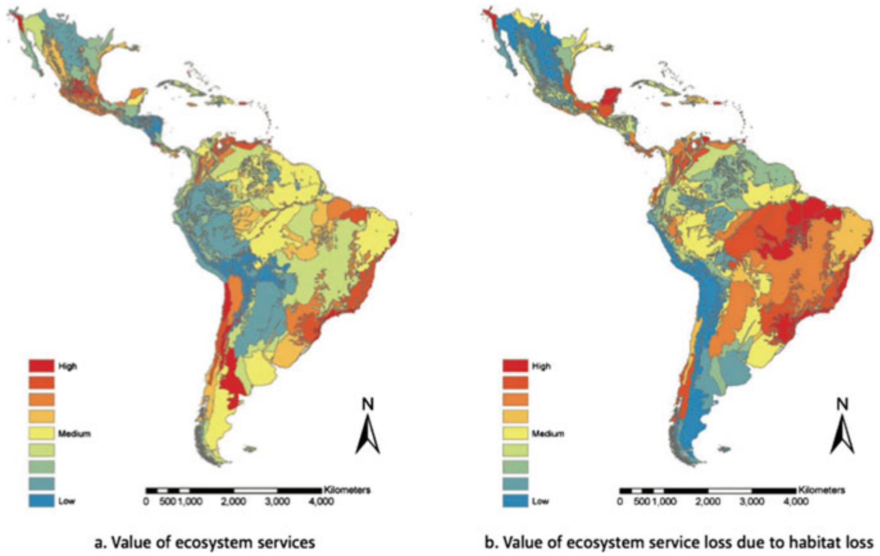

Fig. 5 Predicted value (per hectare) of ecosystem services and loss in ecosystem services due to habitat loss, 2000–2010 (Mekonnen et al. 2015)

Structure of the Curriculum

The curriculum will be structured in modules, based on the data collected for the WATERMAS inventory. The general approach to the structure of the curriculum is based on the following modules:

First semester (theoretical)

Module 1 Introduction to IWRM in the LAC region
Module 2 WR conservation and ecosystem services
Module 3 Circularity: Multifunctional land use and reuse
Module 4 Climate change, climate impact, climate adaptation
Module 5 Engineered and nature-based solutions for sustainable water and land management

Second semester (practical)

Workshop 1 Applying IWRM on catchment scale (project seminar)
Workshop 2 Development of a climate adaptation strategy on catchment scale (project seminar)
Workshop 3 Water-Energy-Food Nexus and Public Participation

Green Campus—The Living Lab

The universities campus should play a key role in the water management and climate change master programs as it is part of the student's real life system, and could be used as living lab for the development of the practical part of the curriculum. A living lab is a place-based research concept that utilizes the college campus as test-bed for innovation and knowledge generation, representing the campus as a pilot site for climate adaptation. A green campus is a challenge as it means using the built environment to revitalize college education as a form of experimental learning. A feasible guideline for such activity is the Greening Universities Toolkit of the United Nations Environment Programme (UNEP 2010).

Teaching and Learning Methodology

General Didactic Approach—Students Become Self-Directed Learners

Three main goals characterize the approach to curriculum development in the WATERMAS project (in analogy to Leat 1998):

- the development of flexible, adaptive learning methods and types of tasks that transform WR management into a challenging and exciting subject
- to help students to understand important key concepts of thinking in WR management and develop cognitive skills that they can apply in a different context,
- To support the intellectual development of students so that they can better handle diverse and complex information in the study and beyond.

In order to achieve these goals, the WATERMAS project will develop learning methods and exercises that will motivate students to reflect and think in a motivating systems thinking way. Decisive is always the thinking process, which leads to the solution of the tasks. That is why each task has a reflection in which the students themselves should become aware of this thought process (metacognitive learning; Ambrose et al. 2010; Barkley 2010). Working with learning methods also opens the way to a self-directed way of thinking that goes beyond the specialist content of WR lessons. The following thinking strategies play a central role in this context:

- *Compare:* Find similarities and differences
- *Link:* Search internal and external connections
- *Locate:* Map phenomena geographically and assign them
- *Change of scale:* Consider phenomena on different scale levels
- *Change of perspectives:* Analysis of phenomena in multiple perspectives
- *Deduce and induce:* Connect the general and the specific.

Water and Climate Cycles—Circular Thinking

Nature's systems are based on cycles, and water and climate are prominent examples for natural cycles. Sustainable systems are based on balanced cycles that do not produce waste. After the development of the cradle-to-cradle (circular) concept by Braungart and McDonough (2002), water management was one of the key implementation fields for circular economy principles. Circular economy in water management include waste water reuse and roof water harvesting. The learning methodology intends to develop students' insights into circular approaches as such and in analogy to natural ecosystem cycles. The teaching methodology is based on circularity: the knowledge value chain.

Climate Change and Climate Impact Mitigation—Systems Thinking

Main focus of the teaching and learning methodology is to overcome fragmentation in (a) WR management and climate adaptation approaches, and (b) teaching and learning approaches. To achieve that, the framework for the teaching and learning methodology is a Nexus approach, mediated through systems thinking.

In the last years increases the awareness of the complexity of environmental problems and led to the development of new management approaches. Pahl-Wostl (2007) proposed to focus on the transition to new management paradigms for systems to be managed that are complex and adaptive. Systems thinking refers to a holistic approach that recognises the tendency in nature to form 'wholes' that are more than the sum of the parts by ordered grouping. While IWRM as a reductionist approach tends towards breaking down complex systems into simple constituents (Dzwairo et al. 2010), a Nexus refers to a link or set of links that link two or more things or topics. At the 'International Kick-off Workshop: Advancing a Nexus Approach to the Sustainable Management of Water, Soil and Waste (WSW)' in 2013 the WSW Nexus was hence described: "*The Nexus Approach to environmental resources' management examines the inter-relatedness and interdependencies of environmental resources and their transitions and fluxes across spatial scales and between compartments. Instead of just looking at individual components, the functioning, productivity, and management of a complex system is taken into consideration*" (UNU FLORES 2015; Avellan et al. 2017).

The management of natural resources through a Nexus approach has gained significant importance in the last years. The main Nexus approaches are summarised below. They will form the didactic framework for the transfer of the systems thinking to the learners. The Nexus' perspectives below are referring particularly to WR, climate change and the teaching of these subjects in an LA context, and show the systems thinking dimensions.

***The WR dimension: Water-Energy-Food Nexus* (Hoff 2011; Huelsmann and Ardakanian 2014; UNU-FLORES 2015)**

The Water-Energy-Food (WEF) Nexus assesses the interdependencies between water, energy and food security for human well-being and intends to achieve all three of them in an equitable manner. The Nexus approach is based on the understanding of the synergies and the regulated negotiation of fair trade-offs between competing uses of water, land and energy-related resources (Schneider et al. 2018a). A particular WEF approach for transboundary river basins was developed under the UNECE Water Convention for the 2013–2015 program, that is the Transboundary River Basin Nexus Approach (TRBNA) (de Strasser et al. 2016).

***The land use dimension: Water-Soil-Waste Nexus* (Avellan et al. 2017)**

The Water-Soil-Waste (WSW) Nexus complements the WEF Nexus (UNU Flores 2015), and asks how resources should be managed to tackle sustainable management. The addition of waste as a resource dimension that often gets omitted in the sector based approaches shall arguably result in more effective and efficient solutions to problems (Avellan et al. 2017).

***The climate adaptation dimension: The Land—Climate—Energy Nexus* (Dale et al. 2011)**

The Land—Climate—Energy Nexus focuses explicitly on the intersectoral dependencies of competitive land use, energy production and the related climate change impacts, based on an integrated analysis of climate change, land-use, energy and water strategies for mitigation and for adaptation purposes.

***The resources dimension: The Minerals—Energy Nexus* (McLellan 2017)**

The Minerals-Energy Nexus according to McLellan (2017) describes the interlinkages between the extraction and use of mineral resources and the necessary energy supply, underlining energy as necessary resource for the minerals production, but also the necessary minerals to produce energy. The Minerals-Energy Nexus has also a WR dimension in the moment when minerals are extracted from catchments, and particularly from rivers. This interlinkage was recently illustrated by Schneider et al. (2018a) using the example of the sand extraction from rivers in South East Asia and the impact of water power stations as barriers for the sediment transport.

***The educational dimension: Teaching-Reserch-Practice Nexus* (Schneider et al. 2018b)**

Like three-bottom-line of sustainability includes social, ecological and environmental issues, the Teaching-Research-Practice Nexus (TRPN) describes the co-equal existence of teaching, research and practice in institutions of Higher Education. As a framework for the implementation of sustainability in Higher Education, the TRPN is intended to lead to the integration of an intensive reference to practice in teaching and research.

The regional dimension: Spaces-Practices-Goods Nexus **(Schneider and Popovici 2018)**
The Spaces—Practises—Goods Nexus in the light of water resources refers to the sustainable consumption of locally produced goods representing the regional identity, which promotes the valorisation of regional value chains of sustainably produced goods.

The project intends to open up a complementing Nexus dimension, the ***Society-Education-Research Nexus***, which describes the socio-economic dimension of sustainability implementation approaches, particularly through educational activities. The Society-Education-Research Nexus describes the interlinkages between the conditions for the resilience and adaptive capacity of a society, promoted through formal and non-formal education for capacity building on water resources conservation and climate adaptation, based on state of the art research.

Integrated Water Resources Management—Practical Application

As mentioned above, the curriculum shall include teaching as well as a practical application on IWRM, based on particular regional data bases for river basins in Cuba and Ecuador. The pilot catchments for practical education shall serve as modelling site for water resources and conservation as well as for the stakeholder analysis to understand the real life problems of competing water uses. In the ideal case, the pilot catchments can be used for the stakeholder participation process under the Water-Energy-Food Nexus perspective.

Administrating Water Resources—The Institutional Dimension

The conservation and sustainable use of water resources is based on the provision that water resources are managed and administrated properly in order to avoid over-exploitation and pollution. For a sustainable administration is the establishment of reliable, transparent and functionable institutional settings, which includes a sufficient administrative structure acting under the requirements for good governance. WATERMAS will outline key aspects for the institutional dimension.

Protecting Water and Biodiversity Resources—The Social Dimension

The protection of water and biodiversity resources that are essential for the long term provision of water-related ecosystem services. Capacity building in terms of water and biodiversity resources conservation can support the awareness development for this problem. WATERMAS will outline key aspects for the social dimension and how to prepare capacity building to rase awareness for the protection of water and biodiversity resources.

Valorising Water and Biodiversity Resources—The Economic Dimension

Water is a good for nutrition, and the protection of water resources requires its valorisation in economic terms along the product value chain. Therefore, information on water extraction and distribution investments, water treatment methodologies and their operational cost as well as on resulting tariffs for the water consumer must be included. Relevant are also innovative water conservation strategies like payment for ecosystem services (PES). WATERMAS will outline key aspects for the economic dimension, under consideration of the environmental and institutional dimensions.

Engineered and Nature Based Solutions for the Mitigation of Climate Change Impacts and Disasters—The Engineering Perspective

By now, the majority of solutions for mitigation of climate change extremes and disasters are engineered solutions, like high tide reservoirs or dams. On the way to the implementation of sustainable development solutions, the International Union for Conservation of Nature and Natural Resources (IUCN) fosters nature-based solutions (NbS) to address global societal challenges (Cohen-Shacham et al. 2016). According to Cohen-Shacham et al. (2016), nature-based solutions use ecosystems and their services to address challenges like climate change, food security or natural disasters. IUCN defines NbS as: "*Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*."

Examples of nature-based solutions for climate protection and adaptation include the conservation of peatlands as important CO_2 storage, the renaturation of flood-plains as retention areas to mitigate flood peaks, and the use of urban green to retent heavy rainfall events in cities. WATERMAS will provide key aspects for the implementation of the engineering perspective in the curriculum.

Internalisation of Externalities—The Environmental Perspective

Water disagreements can occur when opposing interests concern the fair distribution of water resources and especially, when they are superimposed by externalities, e.g. a situation that influences the welfare of individuals or a community (Young 2000). Typical externalities that lead to water disputes or conflicts are upstream-downstream problems (Kelsey 2009), like water pollution or missing flood risk management that impact the downstream user. The way to resolve externalities in a sustainable way is the internalisation of the externalitie's cost back to the causer of the externality, based on the polluter-pays-principle. In case of transboundary water resources, the resolving of water disputes through internalisation of externalities is supported by hydropolitics. WATERMAS will outline key aspects for the environmental dimension, under consideration of the economic and institutional dimensions.

Conclusions

Natural resources and biodiversity are essential to the economies of the LAC region, where the many threats of climate change to water and biodiversity conservation pose a serious risk to their socio-economic development. Scope of the WATERMAS project is to address these aspects through the development of international master programs on water management and climate change. The project will develop and establish a new standard of higher educational and scientific knowledge exchange between European and LAC countries. This will be done leveraging existing Master's courses/programs of Water Management at the partner universities.

The water-related challenges facing the LAC region have to do with variations in climate and hydrology and with the administrative level to which the management corresponds. Other factors with equal or greater importance are the differences in the nature and effectiveness of the institutional systems, the disparities in the distribution and demographic structure of the population and macroeconomic factors related to world trade. An increase in water abstraction due to increasing population and economic development is expected above all in the LAC region.

The WATERMAS project addresses these challenges under the Teaching-Research-Practice Nexus (TRPN), particularly the Sustainability Development Goals (SDG) 4 (Quality Education), 6 (Clean Water and Sanitation), 11 (Sustainable Cities and Communities), and 13 (Climate Action). The scope of WATERMAS is to implement sustainability approaches in the curricula of higher education institutions through the development of (key) competences that make it possible to act with a future-oriented and global perspective (Adomßent and Michelsen 2006; Mochizuki and Fadeeva 2010; Rieckmann 2012).

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Mangrove Conservation Policies in the Gulf of Guayaquil

Daniel Ortega-Pacheco, Maria J. Mendoza-Jimenez and Paul Herrera

Abstract In the last decade, the Ecuadorian government has designed and implemented a variety of policies to enhance the conditions of mangrove forests and their ability to provide ecosystem services. The present work aims to identify the different policies related to mangrove conservation and evaluate the extent to which they produce different outcomes to the population in the Gulf of Guayaquil, a coastal region hosting more than 70% of mangroves in Ecuador. The main assumption underlying this effort is the notion that mangrove conservation might be critically linked to subjective measures of welfare improvement for populations that live in and depend on this ecosystem, in addition to their original conservation purposes. Based on evidence of recent studies, an institutional economic analysis using the Situation, Structure and Performance framework is conducted. Results report evidence supporting the original assumption, as well as identified challenges to the continuity of current policies and new but urgent avenues for future research.

Introduction

The Gulf of Guayaquil (GG) represents an exceptional case study whereby the need for development meets the need for mangrove conservation. Around 71.4% of the Ecuadorian mangrove extension is located in this area (Bravo Cedeño 2010). Mangrove resource users deal with high levels of unsatisfied basic needs, poverty,

D. Ortega-Pacheco · M. J. Mendoza-Jimenez (✉)
Centre for Public Policy Development, ESPOL Polytechnic University, Escuela Superior Politécnica del Litoral, ESPOL, Faculty of Life Science, Campus Prosperina, Guayaquil, Ecuador
e-mail: mjmendoz@espol.edu.ec

D. Ortega-Pacheco
e-mail: daviorte@espol.edu.ec

P. Herrera
Faculty of Life Science, ESPOL Polytechnic University, Escuela Superior Politécnica del Litoral, ESPOL, Faculty of Life Science, Campus Prosperina, Guayaquil, Ecuador
e-mail: aherrera@espol.edu.ec

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inadequate housing and inadequate waste management (Herrera et al. 2017). Small-scale fishing is the main source of income in the communities and it is organized in fishing associations. Around half of these products are sold to intermediaries and the rest, in markets located in Guayaquil, Machala, and Playas. Mangrove extraction is commonly destined to wood and carbon industries, construction and handcrafts (CI 2016a). Tourism is another income source that demands food service, supplied by local fisheries, but generates considerable wastes (CI 2016b). Additionally, a great number of commercial productive activities, especially those involving shrimp farming (Bravo Cedeño 2010), take place around these populations, and they also face the pressure of densely populated urban cities—with their associated pollution, such as Guayaquil (Montaño and Robadue 1995).

There is an increasing necessity to generate valuable information to inform policy design that allows tackling sustainability challenges in the GG, for it is also the same location where most of the Ecuadorian marine biodiversity seems to exist (Cruz et al. 2003). This area is being threatened by increasing rates of loss of species, such as birds (Alava and Haase 2011), as well as ecological and socio-economic factors (Twilley et al. 2001), such as Urban, industrial, agricultural, as well as other aquaculture development (Alvarez-Mieles et al. 2013). Environment and water quality are particularly sensitive to changes in the use of land (Twilley et al. 1998). This fact becomes relevant considering that, according to (Cuesta et al. 2017), conservations loopholes/voids have been identified precisely in zones located in the central and southern coastal areas.

Empowering and strengthening laws and regulations is necessary to achieve a legal protection of endangered species and the conservation of the ecosystem. Decentralizing the management of protected areas may contribute to this purpose, by improving the provision and impact of public services through an increased role of communities and local governments in the decision-making (Wright et al. 2016). According to official statements from organisms such as the Ministry of Environment (MAE), there is political will among Ecuadorian authorities to explore a decentralized management system that transfers responsibilities and benefits as a mean to preserve environmental services that benefit the present and future users of the mangrove (MAE 2013). On this respect, there exist ongoing endeavours to design a network of marine protected areas that adapts to an institutional context and empowers different government levels to interconnect fragmented areas of the ecosystem and benefit user populations (CI 2016a, b). This must be evaluated in a double context, where (i) mangrove user communities continue living in considerable levels of poverty and their income via cash transfers will likely reduce due to budget restrictions. And (ii) there is a growing interest in benefits that can be obtained from carbon sinks (Hamilton and Lovette 2015) and protection against floods (Frappart et al. 2017)—particularly in Guayaquil, the world's third city with largest impact on GDP per capita due to climate change (Hallegatte et al. 2013; Reguero et al. 2015). Both services (sink and protection) could help develop a redistribution system of benefits in exchange for compensations that weigh-off the opportunity cost of conservation, and help improve life conditions of mangrove users and those who depend on that ecosystem, within and outside the GG.

During the last decade, the Ecuadorian government has designed and implemented set of public policies aiming to improve mangroves' health and their capacity to provide ecosystem services. The assumption underlying these actions is the idea that mangrove conservation may be related to an improvement of local welfare within the population that lives and depends on this ecosystem. In particular, populations that cohabit with mangrove ecosystems execute actions that allow them to improve their life conditions, and thus their well-being. These actions are related (1) with resources that the policy claims to preserve and (2) the ways in which the community can organize in general to achieve their objectives, specifically, in relation to the implementation of public policy (Andersson and Gibson 2007).

The extent to which policy objectives are met is the result of a dynamic where the subject of the policy, the community, plays a double role as both origin and destination. This, in turn, evidences the need for a careful analysis of experiences from each community in order to replicate the path obtained from successful case studies (Miteva et al. 2012). From this perspective, the present work attempts to answer the recent, yet global call (Brockington and Wilkie 2015) to further evaluation studies that pave the way for improving the understanding of how different political instruments produce distinct outcomes for populations. Based on locations in the GG, this paper explores the relationship among three types of governance schemes [(i) centralized, (ii) decentralized or communal, and (iii) decentralized or communal with centralized incentives], different categories of protected areas, conservation practices and their impacts in human welfare. The analysis derives from an exploratory analysis of secondary information. First, a critical revision of multiple sources that include peer-reviewed publications, official and academic studies, as well as reports and documentation on public policy. In addition, a recently completed study by Herrera et al. (2017) provides updated input to understand the perspective from which beneficiaries of mangrove forests in the GG evaluate conservation policies. This work has been designed as to provide baseline information that will allow deeper understanding of how public policy may impact human welfare, i.e. fishermen and collectors in the GG.

The study continues with a second section in which mangrove-related policies relevant to our area of study are presented chronologically. The third section describes the different policies in consideration. The fourth section explores the state of implementation of the policies from a critical perspective of the interaction of three spheres, by arranging the information collected so far into a Situation, Development and Performance scheme proposed by Schmid (2004), a tool that allows for the analytical assessment of an institutional impact. Preliminary reflexions will be procured in order to identify future options for the design, implementation, evaluation and improvement of mangrove conservation policy in the area of study, which will be presented in the end. The understanding derived from this analysis may inform policy-designers involved in mangrove conservation and welfare improvement in Ecuador.

Chronology of Policies Relevant to the Study Area

According the Ecuadorian Constitution of 2008, the population has the right to live in a safe and balanced environment (Art. 14), and the State should procure the conservation of nature by means of programs in which communities participate (Art. 57). From a legal perspective, the State acknowledges and guarantees nature's rights (Art. 71). Environmental legislation of 2003 reaffirms that mangrove conservation is in the public interest and thus, prohibits its destruction or exploitation. In addition, ancestral communities are allowed to request permission to serve as "mangrove guardians".[1]

A chronological revision of the legal framework related to mangrove conservation in Ecuador identifies three periods relevant to this research. Each of them is characterized by the assigned role to mangrove land, the allocation of extraction rights and its assessed social value.

(1) 1970–1985: Between 1976 and 1979, unexploited lands were taken over, and the redistribution of land forced the expansion of agricultural borders amidst landowners, who did not want to lose their underused but biodiversity-rich territories (IICA 1990). Furthermore, permissions were granted to shrimp farmers to promote the productive transformation of those territories (Coello et al. 2008).
(2) 1985–2010: In 1985 the conservation, protection and reposition of mangrove forests were declared "in the public interest", via presidential decree and environmental law reforms. In 1999 the government conceded ancestral communities the right to request "custodia" (Acuerdos de Uso Sustentable y Custodia del Manglar) agreements. In 2000, the MAE communicated the guidelines to concede custodias to ancestral communities and traditional users.
(3) 2010–present: A decade later in 2011 the MAE determined the economic cost for the loss of environmental goods and services—including restoration costs—provided by mangrove forests: \$89,273.01/ha. In 2014, a new instrument with monetary incentives was introduced to promote the conservation and sustainable use of mangrove forests: Socio Manglar, an extension of the program Socio Bosque. Socio Manglar attempts to complement, consolidate and improve the results achieved by the previous custodias in a way that guarantees conservation, while enhancing life conditions for users. By January 2017, 23 Socio Manglar agreements were active in the coastal region.

The evolution of the Ecuadorian policy for mangrove conservation is marked by year 2000 as the continuation of a neoliberal trend in the context of usage of natural resources and ecosystem services (Beitl 2016), which in turn emerged like a potential

[1] During the final stage of the elaboration of this paper, the new Organic Code on the Environment was issued in Ecuador, motivated by the necessity of harmonizing and organizing the multifold and complex national legislation. The understanding of this dynamic is satisfactory: the unavoidable fact that this new legal framework will modify the competences of regulatory entities and guarantors of mangrove conservation; as well as the interaction with user communities and subjects of public policy.

solution to the conflict of land usage between shrimp farmers and mangrove custodias. The introduction of new policies implies the introduction of new systems of incentives. The identification of these incentives is necessary to determine the extent to which results may be attributed to the objectives of the policy, which in addition to resource conservation, seek welfare improvement in the communities involved.

Stylized Facts of Policies Implemented in the Area of Study

In the present study, public policies are considered, according to Article no. 85 in the Constitution, as instruments oriented to implement the Ecuadorian rights, including the concept of "Buen Vivir". Such instruments include formal institutions (i.e. norms, regulations) that have been designed, implemented and evaluated by the organisations involved in mangrove conservation.

The policies were selected according to a criteria related to the impact or incidence capacity of the policy in the selected mangrove areas. They have been applied to different levels, allowing for a comparison of their respective efficiency to alter human welfare. It must also be mentioned that this study has not considered policies that directly targeted welfare and could have additionally impacted the mangrove ecosystem positively. In order to meet the objectives, the analysis will focus on the policy instruments described in Table 1.

The protected areas are managed by the government (centralized), represented by the MAE and its local offices (State). Thus, they operate under prescriptive regulatory tools, known as command-and-control regulation. On the other hand, mangrove areas granted as custodias belong to the State, but their administration has been delegated to the organization that signed the agreement (decentralized). Upon approval of a proposed management plan, the government grants local mangrove users the access to consumption and commercialization of mangrove resources, mainly crabs and clams. Thus, this is an instrument in which actors participate voluntarily in co-management with the governmental authority. Custodias are numerous but small in terms of extension. Associations that have been granted a custodia are eligible for the third type of policy: Socio Manglar program, which provides a monetary transfer conditioned on the implementation of a yearly investment plan, in addition to the management plans.

Table 1 Public policies in the Gulf of Guayaquil

Instruments	Protection categories UICN[a]	Governance	Incentives structure	Management practice	Implementing body	Established
Protected Areas						
Reserva de Vida Silvestre El Morro	IV	Centralized	Command-and-control compulsory instruments	Management plans with zonification	State	2007
Reserva de Producción Faunística Manglares El Salado	VI					2002
Custodias						
Custodia agreements	[b]	Decentralized	Instrument with community participation (co-management)	Management plan and utilization plan: closure dates and monthly contributions	State and fishermen associations 6 de Julio, Cerrito de los Morreños and Balao	2007 2011 2016
Payment for ecosystem services						
Socio Manglar	[b]	Centralized	Instruments based on incentives (cash transfers)	Investment plan	State and fishermen Association 6 de Julio	2007

[a]Modified from Ulloa et al. (2007)
[b]Sustainable use of mangroves, category of the National Forest Heritage

State of Implementation and Effects of the Main Mangrove Conservation Policies in the Gulf of Guayaquil

This section analyses how the policies could have impacted the health of mangrove forests and their associated ecosystem services. Theory-based hypothesis will be identified, which will be preliminarily explored by using evidenced obtained by Herrera et al. (2017) and similar studies carried out in the past.

Once having described the conservations policies, the Situation, Structure and Performance (SSP) analysis framework may be applied. Such a tool is useful to evaluate and compare instruments in contexts that take into account performance and institutional relations (Wells 1998). The SSP framework, proposed by Schmid (2004), allows for the specification of relations and description of attributes of goods and services that create human and ecosystem interdependencies (situations); the exploration of characteristics of alternative institutional arrangements (structures); and, the evaluation of the relative effectiveness between those alternatives with respect to the socially desirable objective (performance). The analysis furthered below is summarized in Table 4.

Situation

Within this analytical framework, the elements that relate to each other in order to build up the situation, are identified as: transaction (unit of analysis), interdependencies and stakeholders (government, communal organization and users). A transaction is an interaction space between individuals and contexts in which costs are always involved. In this case, the reference lies on the provision of mangrove conservation and its relation with ecosystem services to fishermen residing in the communities within the area of study. Such services include reproduction and feeding of different kinds of fish, molluscs and crustaceans of considerable importance for good nutrition and as a sustainable economic source.

Three key interdependencies that seem to emerge in fishing communities in the GG, as hinted by the characteristics of mangrove services and actors involved in transactions of conservation provision: (1) potential incompatible or alternative use of the mangrove for extractive purposes, reaching the point where the quantity and quality of the catches are affected; (2) price problems associated with the provision of conservation services, where the marginal cost of additional users is too low when compared to the very high cost of exclusion of extractive users from neighboring communities; and (3) lack of information regarding transaction costs.

A systematic analysis of the problem of incompatible use of the mangrove with regards to all economically relevant species according to the inhabitants of the communities, is out of the scope of this study. What is being discussed is the incompatible or alternative use of the mangrove for extractive activities related to clam catching by affiliated members of the considered associations that have been granted a custodia. It suffices to mention that, first, the interdependencies emerging from the incompatible use of mangroves are linked to questions related to property rights over the extracted resource. Solutions to this problem, once the extraction rights have been allocated and effectively restricted, will essentially depend on whether the continuous use of mangrove for extraction purposes contributes more to members of the community (or external users) than the negative impact on the revenues of affiliated members. Consequently, associates might consider accepting a payment for discontinuing the non-compliance of fishing closures and respecting extraction rights or implementing surveillance activities in joint cooperation with the public force and environmental authorities, in such a way that private practices of a user do not affect others'.

Secondly, while the extraction of clams is a service subject to consumption rivalry (i.e. Fisherman man A may not share the catch obtained by Fisherman B), the marginal cost of admitting an additional member is virtually zero, once exclusive extraction rights have been allocated, following an optimal distribution scheme that respects population dynamics of the resource. Additionally, a certain level of joint consumption of the clams' quality can be observed, i.e. all members should obtain the same quality in a system of extraction rights. Allocating rights and identifying the optimal fishing level are characterized by high fixed costs and almost null costs of incorporating an additional user. For this reason, the price of extraction rights should allow for the distribution, among all users, of the—relatively—high fixed costs associated with the design, implementation and administration of the system of extraction rights.

Thirdly, incomplete information on mangrove conservation and its effect on the quantity and quality of the catch may hinder the service provision, as well as affect costs of transaction. Although it is possible for fishermen associations to control the catches of its users by keeping track of the quantity and sizes of their catches, determining and monitoring the extraction of non-members and foreign fishermen is more complicated, if not impossible, or at least very costly. This is particularly important when considering the lack of technical and scientific information related to optimization of the catch of clams and its population conditions. In many cases, associated and non-associated users ignore the specific steps that must be undertaken in order to achieve a certain quantity and quality of the catch, contributing to the level of uncertainty and transaction costs associated to the de facto arrangements between the association accountable for the custodia and its neighbors, including fishermen from other regions, also known as independents or pirates (i.e. free riders).

Structure

The alternative structures presented include: (i) command-and-control compulsory instruments of direct action as in the case of protected areas; (ii) indirect action instruments with decentralized governance schemes created to reconcile community development and conservation by promoting the sustainable use or alternative income sources such as custodias (i.e. co-management); (iii) direct instruments with economic incentives conditioned on assessable performance, which is presumably able to achieve additional progress by linking conservation and development, as in the case of Socio Bosque (i.e. co-management with cash payments as incentives).

Performance

In this section, the characteristics of the alternative institutional arrangements—-types of policy instruments for the management of mangrove areas—will be considered in order to eventually make predictions about their likely outcomes. Following these predictions, a discussion regarding the expected future performance of these structures in the considered associations, will be furthered. Potential strengths and weaknesses of the policies will be identified, considering the recent data obtained by Herrera et al. (2017) and similar works in the past.

According to Miteva et al. (2012), the diversity of impacts caused by decentralized policies is explained by the ambiguity of the term "decentralization". The implications of a decentralized policy may vary in terms of the policy's scope, the perceived benefits, the rights granted to the different populations and also, the decision power—increasing the authority of bureaucrats at lower levels or the authority to local users (Larson and Soto 2008). Many developing countries have transitioned towards decentralized forestry governance schemes during the last 25 years (Phelps et al. 2010), on the premise that rights and responsibilities of local actors would increase (Agrawal and Ostrom 2008). In fact, decision-making autonomy at a local level is associated with greater levels of ecosystem services (i.e. carbon) and greater benefits to living conditions (Chhatre and Agrawal 2009). Despite successful experiences, several authors state that the decentralized implementation still faces big challenges: inefficiencies and weaknesses in the legal and institutional frameworks have resulted in mismanagement and misappropriation; a high degree of non-compliance; conflicts among users; and tension and lack of trust among the different levels and sections of the government. These factors have resulted in the weakness or lack of empowerment of the poorest users in the system (Wever et al. 2012). In a recent study, Wright et al. (2016) point out that decentralization may positively impact deforestation while involving communities and local governments, by relating their interests with local political actors and their corresponding agendas.

In the case of Ecuador, Beitl (2017) argues that it is critical for the success of custodias to empower fishermen with administrative rights. Despite the fact that they promote quantitative and qualitative improvements of the catch, they could also limit access and mobility of fishermen, which could result in a reconfiguration of fishing areas and displacement of non-members from their customary work space. In fact, current policies might not seem to introduce enough individual incentives to abide by the regulations, but they do seem to introduce enough incentives at group level to safeguard the base of the resources, that is, the habitat. The improvement of the habitat's conditions should cause indirect and positive effects in fishing activities (Barbier 2003). This way, explains Beitl, the policies seem to have promoted a notion of group appropriation that has fostered care for the environment.

An integral assessment of the results obtained by these policies is outside the range of this study, however there are a few available. Among these few, the study of Coello et al. (2008) stands out for evaluating 26 custodias granted between 2000 and 2004. Despite the problems outlined and the diversity of results, general positive effects were observed: empowerment of associations, increase of fishing output, enhancement of living conditions, decrease of mangrove deforestation and conflict resolution with shrimp farmers. Technical assistance provided by non-governmental organizational has been relevant in successful custodias.

The recent work of Herrera et al. (2017) provides updated data on the perception of the effectiveness of the three instruments, according to fishermen residing in the Gulf of Guayaquil. Table 2 shows a detailed summary of the studied locations and approximate population of fishermen and collectors, according to each policy. Figure 1 shows the geographic locations of the study.

The gathering of primary data involved the application of a questionnaire completed by a sample of 435 individuals during February to November 2017; the estimated universe was 2138 fishermen and collectors. The elaboration of the survey was previously designed and tested with input obtained from focus groups in which key actors (among others, local authorities, non-governmental actors, governmental actors, fishermen, collectors) took part.

The study concludes that the policies have favoured the protection and restoring of mangroves in the GG (approximately 1515 ha) during the period 2002–2016, compared to locations in the GG where no policies were implemented. Table 3 summarizes the results from the survey related to perceptions of the effectiveness of the policies under analysis.

Table 2 Locations in the GG selected for the study and corresponding population

General identification	Mangrove conservation policy applied	Location	Sub-location	Approx. population of fishermen and collectors
Conservation unit	Custodia or mangrove concession + Socio Manglar	6 de Julio	6 de Julio, La Unión and Las Mercedes	177
	Custodia or mangrove concession	Balao	Balao	417
		Don Goyo	Cerrito de los Morreños	152
			Santa Rosa	96
			Puerto Libertad	156
			Tamarindo	50
			Bellavista	60
	Protected Area	Puerto El Morro	Puerto El Morro	750
		El Salado	Playita del Guasmo	100
			La 49 y Rosendo Avilés	120
	None (control group)	Masa 1	Masa 1	60
	Total			2.138

Elaborated by Authors
Source Data provided by local authorities during workshops

Table 3 reports:

1. Awareness of the existence of the policies (Yes or No) is associated to the type of policy, the location and whether the individual belongs to an association or not. The results indicate that those surveyed within areas under custodia agreements and protected areas do know about the existing policies. Respondents in the locations of Balao and Masa know less or nothing about them. Members of associations know more about the programs than those who are not affiliated.
   The perceived benefits of the program furthered by the policy include: protection of water quality (25%), increase of job opportunities (25%), enhancement of fish quality and protection of wildlife (18%). Percentages in parenthesis indicate the proportion of the answers that valued that benefit as the most important.
2. With respect to the awareness of mangrove recovery zones, 59% of the surveyed sample identifies them, regardless the type of policy, location, or state of affiliation. When consulted which institution they believed to be responsible for the protection of mangroves, 62% of the sample mentioned MAE; 32%, the community; and 3%, the municipality.

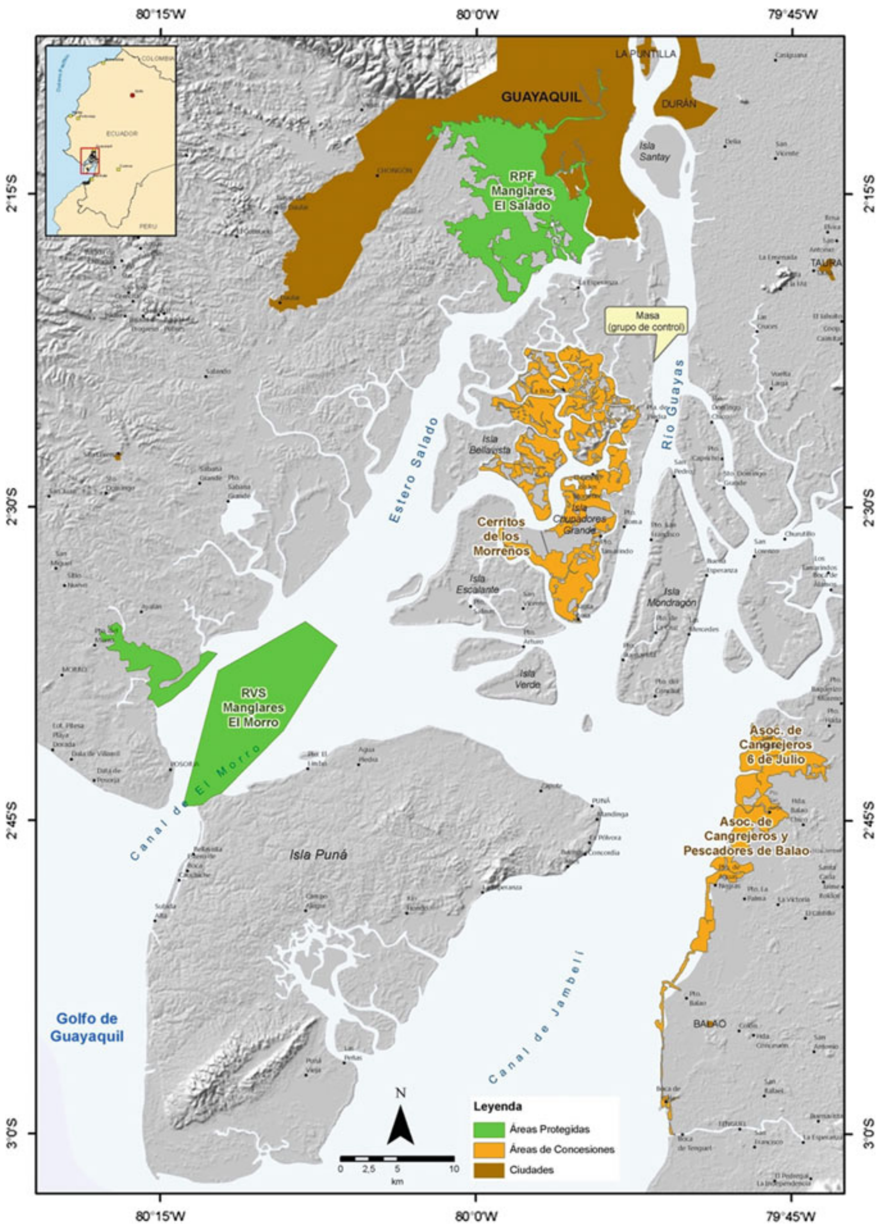

Fig. 1 Locations included in the study. *Source* Herrera et al. (2017)

3. Respondents were asked to rank between 1 and 5, being 5 equivalent to "completely agree", how effective they considered governmental measures to be, in terms of contribution to: the community, mangrove conservation, harvesting of

Table 3 Independence tests between perceptions about public policies and type of policy, location and state of affiliation

Question	Variables		
	Type of policy	Locations	State of affiliation
Awareness of the existence of the policy[1]	A relationship exists	A relationship exists	A relationship exists
Identification of recovery areas[2]	A relationship does not exist	A relationship does not exist	A relationship does not exist
Effectiveness perception about governmental actions[3]	A relationship exists	A relationship exists	A relationship does not exist
Awareness of the existence of Socio Manglar[4]	A relationship exists	A relationship exists	A relationship does not exist

Chi-Sq. tests were run in order to determine the independence or association between each question and the variable. All statistical relations were verified at a 95% confidence level
Source Herrera et al. (2017)

species, and livelihood enhancement. T-tests revealed that the answers to these questions did differ according to the type of policy and location, but not in terms of state of affiliation. Answers were less favourable in the case of the control zone, Masa.

In order to know the importance that the fishermen gave to a list of potential governmental measures, they were asked to rank the following options. Numbers in parenthesis refer to the proportion of answers that partially or completely agreed with that measure.

- Improve communal organization (98%).
- Take advantage of the communities' experiences to protect mangroves (97%).
- Promoting affiliation to associations (96%).
- Complete a study to identify potential output (92%).
- Increase the number of protected areas and custodias (89%).
- Implement closures for clams (84%).
- Restrict access to fishing zones to surrounding communities (77%).
- Increase the number of closures for crabs (51%).

4. Regarding the awareness of the existence of Socio Manglar, 27% of the sample confirmed knowing it. An association between this information and the type of policy and location was verified. Within areas with custodias, Socio Manglar was reportedly identified more that it was in protected areas or the control zone.
With respect to the economic incentive (cash transfer) that characterizes this policy, 98% indicates that his household has not received any payment for the service of conserving the mangroves. 42% of the portion that knows Socio Manglar

reported a neutral stance when evaluating the argument "community resources are well administered".

The information presented in Table 3. has been considered to complete the third column of the SPP framework in Table 4. The performance of mangrove conservation policies in the GG can be condensed with results obtained from the preliminary analysis. Basically, the performance effects reported are observed in the three types of policies at different scales.

About the combined use of incentives to improve the performance of custodias. Empirical estimations based on field experiments in other Ecuadorian regions (Moreno-Sánchez et al. 2015) seem to support the notion that additional revenues from Socio Manglar could be enough to incentivise appropriate behaviour by affiliated users, and additionally pave the way for a collective impact on the ecosystem's health, i.e. program's transfer payment equivalent to the opportunity cost of surveillance, administration, participation in meetings and other activities. Similar to Herrera et al., Moreno-Sánchez' study indicates that users' behaviour is greatly impulsed by motifs such as the well-being of other members of the community—protection of water quality, increase of job opportunities and improvement of fish quality, and in the same line as Beitl's discussion, it was demonstrate that fishermen who were allowed to coordinate actions (including the extension of fishing permits to third parties), extracted 20% less and invested almost twice in administration. Consequently, there seems to be a way to complement direct incentives by strengthening collective action and communication capacities and coordination with the investment of resources from Socio Manglar.

Herrera's work further relates to Moreno-Sánchez, while both studies report evidence that supports the possibility of exploring hybrid systems in which more than one tool or instrument could be combined, allowing the maximization of benefits with the least additional financial resources. In particular, there exist potential benefits of combining custodias with Socio Manglar agreements in communities that have been impacted by ministerial decrees declaring their territories as protected areas. A potential challenge to these hybrid approaches might be transaction costs associated to the identification and implementation of those alternative extraction practices that could result in provable changes in quantity and quality of fish in specific custodia areas.

Previous studies might not compare to Herrera's when considering the effect introduced by large shrimp farms in neighbouring areas, both in ecosystems' health due to quality of the water they dispose and the incentives they represent to weaken community organization, given the potential effect on the demand of collective benefits. The impact of large urban areas in the vicinity of mangrove forests is yet another threat to a habitat's health, which in turn threatens species in terms of quantity and quality. In this context, the positive effect of Socio Manglar may dissipate due to the immediate access to alternative sources of income or disincentives by poaching activities.

Table 4 SPP framework applied to mangrove conservation policies in the Gulf of Guayaquil

Situation	Structure	Performance
Transaction: Service—provision of mangrove conservation and its relation with provisioning service to affiliated fishermen.		Positive perception of the effectiveness of policies and the government
	i. Centralized—protected areas under state administration Protected areas:	Perceived benefits in terms of job opportunities, water, fishing and wildlife protection
Interdependencies: • Incompatible use of the resource and consumption rivalry · Price problems (low marginal cost and high cost of exclusion) • Lack of information of transaction costs	– RPF Manglares El Salado – RVS Manglares El Morro	Positive perception with respect to the importance of fostering a high level of empowerment and responsibility over the resource
		Perceived subjective measures of well-being related to benefits derived from living in mangrove ecosystems
Stakeholders	ii. Decentralized—custodias in co-management between the state and the community	Important scheme and willingness to participate
• Government: complex administrative attributions and jurisdictions		
• Communal organization: Fishermen associations • Users	iii. Decentralized with centralized incentives—Socio Manglar in co-management between the state and the community	Relatively negative perception regarding the appropriate management of funds (weak trust) Unsatisfied basic needs indexes (NBI) have improved, due to the impact of other policies
Characteristics of participants in the interdependencies:		
• Income uncertainty	Control Zone: Masa (No association, custodia agreements or direct influence of a protected area)	Higher level of acknowledgement
• Opportunist behaviour of external actors		High level of solidarity—concern for the well-being of other members of the community

Future Perspectives of Conservation Policies in the GG

The chronological review of mangrove conservation policies, the arrangement of this information into the analytical SPP framework, and finally the comparison of the situation in the Gulf of Guayaquil to foreign experiences and previous national studies, led to the formulation of the following recommendations. These proposals derive from the perceived conflicts in the relations of interdependence between the ecosystem and its users, as well as the identified weaknesses in the management of protected areas and associations as "custodios" of the mangrove, and of course, the availability of information to researchers.

(1) Explore the REDD+ mechanism to provide financial sustainability and fiscal surplus, while decentralizing management and distributing international resources to decentralized governments and communities. Connectivity could be further guaranteed through the Network of Marine Coastal Areas. This may be institutionalized by incorporating it in the renewed management plans and socio-ecological modelling for decision-making (Arias-Hidalgo et al. 2013; Busch et al. 2012; Frappart et al. 2017).
(2) Use of subsidies or tax systems as alternatives of funding for initiatives that have achieved impact (Rode et al. 2016).
(3) Complement with hybrid systems and buffer areas where a sustainable use of aquaculture, geographic origin and improvement of conservation units are furthered (i.e., carbon neutrality in protected areas and custodias) (Alava and Haase 2011; Egelyng 2014; Fisher et al. 2011).
(4) Effectiveness evaluation of each type of instrument (Brockington and Wilkie 2015).
(5) Improve integral planning at an executive level to avoid power and jurisdiction disputes (Wever et al. 2012).
(6) Strengthen the role of organizations that provide technical assistance, such that it includes follow-ups to the agreements (Bravo 2013; Curzon and Kontoleon 2016).
(7) Guarantee exclusive rights and reduce transaction costs by improving information for optimal extraction and implementing a registration system in associations (Aburto-Oropeza et al. 2008; Beitl 2014a).
(8) Facilitate the optimization of fishing portfolio and transfer payments to reduce income uncertainty and high transaction costs (Moreno-Sánchez et al. 2015; Raes et al. 2016).
(9) Construct capacities that builds up confidence and maintain participation by considering the observed impact in the bettering of living conditions (Beitl 2014b).
(10) Productive improvement and income diversification: access to markets without intermediaries and value-aggregation (Clements et al. 2014).

Regarding future perspectives, the financial sustainability of Socio Manglar program is a concern. Especially considering the fiscal conditions of Ecuador in the following years, in light of decreasing oil revenues and increasing foreign debt. Thus, it becomes relevant to consider the exploration of alternative funding mechanisms for initiatives that have proven to impact positively. An option might be the implementation of subsidies or tax systems. Typically, these instruments imply income redistribution among the user sectors and beneficiaries of the healthy conditions of the mangroves, i.e. community collectors, shrimp farmers and urban populated centres.

In order to guarantee changes to human welfare and the ecosystem's health, alternative resources might be sought to maximize the benefits of optimal fishing extraction. An alternative might be technical assistance that expose associations to better practices (e.g. food processing and preservation) along the value-chain, as well as associative capacities for crab and clam extraction through commercial sales (alive and pulp). Gender roles may be empowered considered that men extract and women process, with a better distribution of benefits based on effort and knowledge. Product diversification may involve the sales of decorative and crafty products with added-value.

Conclusions

The discussion presented supports the hypothesis that the impact of mangrove conservation policies might happen by alternative mechanisms different than the provision of larger fishing resources or catches, and instead, they might impact the subjective elements of welfare, such as the potential organizational capacities and increased member participation. Although this is the reality of communities in the GG, they cannot be extended to diagnose the general situation of all peoples under mangrove conservation policies. In this sense, a systematic analysis of a sample of custodias is currently necessary to understand the cultural context in which these mechanisms were implemented, and also identify key factors that explain the resulting level of collaboration, whether it was higher or lower. Future research should also target the improvement of evaluation systems of the studied policies in a context of relations of governances schemes, organization and socio-ecological modelling with a focus on scenery. The resulting information will likely render valuable input for the design of hybrid instruments that combine international resource flows, as well as those from REDD +, and the articulation of management networks of conservation units, deconcentrating responsibilities and benefits while at the same time approach the sustainable use and development needs of user populations. Additionally, incorporating risks and uncertainty in the decision-making process of mangrove users may allow for a better understanding of their relationship with the implementation and effectiveness of the policies under analysis, while at the same time increasing public funds that might be required to outweigh the total cost of mangrove conservation. This measure demands a broad research agenda that is able to incorporate instruments with external and internal validity, and that are replicable in order to generalize findings, as well as explore specific space-time relationships. Overall, the avenue towards the development of appropriate environmental policies, in social and ecological terms, depends on a better understanding of the context.

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Biodiversity Issues Should Be Better Taken into Account in the Energy Transition

Agnès Hallosserie, Hélène Soubelet, Hélène Leriche, Patricia Savin and Jean-François Silvain

Abstract Climate and biodiversity issues cannot be considered one without the other because of the multiple interactions and interdependencies between them. Solutions for climate mitigation relying on the evolution of the energy sector should take this intertwining into account. The French Foundation for Research on Biodiversity (FRB) and ORÉE, a multi-stakeholder NGO advocating the sharing of good environmental practices among stakeholders, explored potential ways to approach the complexity of climate, energy and biodiversity issues in order to develop sustainable solutions. They have been studying the links and interactions between renewable energy and biodiversity through, among others, a conference organized by FRB and a book published by ORÉE. In both the conference and the book, energy producers and suppliers discussed their level of awareness on the issue and presented mea-

A. Hallosserie (✉) · H. Soubelet · J.-F. Silvain
French Foundation for Research on Biodiversity, 195 rue Saint Jacques, 75005 Paris, France
e-mail: agnes.hallosserie@fondationbiodiversite.fr

H. Soubelet
e-mail: helene.soubelet@fondationbiodiversite.fr

J.-F. Silvain
e-mail: jean-francois.silvain@fondationbiodiversite.fr

J.-F. Silvain
Institut de Recherche pour le Développement, 195 rue Saint Jacques, 75005 Paris, France

H. Leriche · P. Savin
Association ORÉE, 75010 42 rue du Faubourg Poissonnière, Paris, France
e-mail: leriche@oree.org

P. Savin
e-mail: savin@dsavocats.com

P. Savin
DS Avocats, 6 rue Duret, 75116 Paris, France

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sures taken to avoid, reduce or offset biodiversity impacts when installing renewable energy infrastructures. This experience sharing highlighted several ways forward in order to reconcile biodiversity protection with the shift towards sustainable energy. Thus, the need to better take biodiversity into account in the energy transition was voiced both by businesses and the research community. This paper presents the first outcomes of the reflections led at the national level by multiple stakeholders, in order to generate further ideas for research to support the design and implementation of integrated climate change and biodiversity policies.

Introduction

Climate change has numerous negative, well-established effects for human populations (IPCC 2014). Solutions to mitigate climate change are now widely promoted across the world, with an increasing urge in the wake of the adoption of the Paris Agreement in December 2015. Action is required in all areas of human lifestyle, including the energy we use and how we produce it. Many European countries, including France, have identified the energy sector as a strategic area to achieve their targets of reducing carbon emissions by developing renewables and phasing out fossil fuels (French Government 2015, 2017). This is known as the Energy Transition.

Biodiversity loss is the other key global challenge faced by our societies, and the result of multiple and varied drivers, including climate change (Ceballos et al. 2017; Crooks et al. 2017; Hallmann et al. 2017). The main driver however is land-use change, natural or semi-natural areas being converted into intensive agricultural lands or cities as global population grow (Tilman et al. 2017). Land is therefore under competition for different uses, including renewable energy production, food production and biodiversity conservation.

In France, the Energy Transition for Green Growth Act aims to reduce GHG emissions and nuclear power, while increasing the share of renewables in the energy mix (French Government 2015). Three complementary courses of action should allow to reach these objectives: energy sobriety, which implies a change of behaviour throughout society; energy efficiency, which is achieved through technical improvement; and development of sustainable energy (Trommetter 2017). These goals, in line with the Paris Agreement, led to the blooming of renewables. In 2015, they provided 10% of energy, including 40% from biomass (Cavaud et al. 2016), these figures highlighting a shift of the sector supported by major stakeholders. In parallel, the law for the reconquest of biodiversity, nature and landscapes (French Government 2016) sets high ambitions in line with CBD Aichi Targets and the Sustainable Development Goals, acknowledging their contribution to human well-being, including for climate mitigation and adaptation.

This paper questions whether the benefits of the energy transition in terms of climate mitigation are not actually contributing to further accelerate the erosion of biodiversity. It first looks at the potential impacts of renewables on biodiversity, and then shows how the recent developments of climate policy in France may reconcile biodiversity and climate policy. Finally, it presents several solutions to mainstream biodiversity into the energy sector, building on science and stakeholders' experience. It builds on existing literature, the proceedings of an event organised by the French Foundation for Research on Biodiversity (FRB) in October 2017 and on OREE's guide (Trommetter 2017).

The Impacts of Renewables on Biodiversity

Renewables differ greatly in the sources they rely on (wind, water, sun, biomass, earth) and the technologies they resort to (e.g. floating or fixed-bottom offshore wind turbines). They have smaller coverage than traditional energy (fissile or fuel) and generate less power per production unit. It means that most renewable energy structures require a wide, dense installation network, affecting ecosystems where they are settled. The energy transportation and storage network adds up to the resulting land-use change, a major cause of the erosion of biodiversity worldwide, and is built with a range of non-renewable metals. Renewables depend on biodiversity for construction (provision of material), energy production, ecosystem services (e.g. water and wood provision), and inspiration through biomimicry. The materials to build the renewable energy infrastructures are transformed through the mining and metallurgy industries which are heavy polluters for ecosystems (Trommetter 2017). The impacts of renewables on biodiversity will therefore vary along those lines throughout their life cycle, and will also depend on the location of the infrastructure (in situ impacts). Ex situ impacts are for the larger part caused by the extraction of material for the construction of the infrastructures, including sand (e.g. for concrete, silicon), rare earths and copper, but also during operation phase when no-go areas (e.g. offshore wind farms) lead to the displacement and higher concentration of pressures (e.g. fishing) elsewhere in the natural habitats. The dismantling of these infrastructures and the recycling of materials are often complex, costly and limited. They have therefore huge impacts at end-of-life (e.g. dams, wind turbines, solar panels) (Trommetter 2017).

If all renewables have an impact on biodiversity, those with the highest ones are biomass energy, which may lead to the destruction of a whole ecosystem, and hydroelectricity, which may cut ecological continuums and prevent the circulation of species (Trommetter 2017). Hydroelectricity is expected to increase by 73% in the next decades, with major dam projects planned on the Amazon, Mekong and Congo rivers. Their watersheds are among the most fragile ecosystems on earth and the three rivers together represent 18% of freshwater fish biodiversity (Zarfl et al. 2015). Solar, wind, tidal and geothermal energy mostly impact biodiversity at the species or individual level. Table 1 largely builds on the synthesis by Gasparatos et al. (2017); Trommetter (2017) and UNEP (2016b) to present for each energy source the processes that could impact biodiversity.

As for nuclear power, France is still a major producer to meet its energy demand (75% of national electricity production), but the existing hot debate around that

Table 1 Potential negative and positive impacts of renewables on biodiversity

Energy source	Potential negative effects	Potential positive effect
Solar power	• Pollution and damage of ex situ ecosystems during resource extraction, including lithium for storage • Disruption during installation phase, operation noise and maintenance • Habitat loss or fragmentation • Bird collisions with the farms • Burnings on birds exposed to intense solar fluxes • Pollution of river and water bodies through runoff of chemicals used for solar panel maintenance and herbicides on the site • Increasing use of water (esp. in deserts) • Bird and insect disorientation through abnormal concentration of light • Ecological trap because of cumulative attractions • Change of local climate	• Nesting and feeding sources for some animals (e.g. pasture)
Land-based wind power	• Pollution and damage of ex situ ecosystems during resource extraction, including lithium for storage • Disruption during installation phase, operation noise and maintenance • Land-use change • Bird and bat collision • Bat trauma due to the change of air pressure around the blades • Disruption of migratory routes for birds and bats	• No-go areas below turbines and a decrease of predators (raptors) favour some terrestrial species
Hydroelectricity	• Worldwide effects of sand extraction for concrete • Disappearance of ecosystems, including natural reserves, and habitat fragmentation when dams are filled • Disturbance of water flows up- and downstream • Disturbance of migratory routes for some fish species • Poorer water quality due to changes of sediment quantity, turbidity and eutrophication • GHG emissions from water tanks	• New habitats or ecosystems

(continued)

Table 1 (continued)

Energy source	Potential negative effects	Potential positive effect
Biomass energy	• Habitat and biodiversity loss, fragmentation, simplification or homogenization due to intensive monocultures • Soil and water pollution because of fertilizer and pesticide use • GHG emissions throughout the production of biomass energy • Change of local climate through change of albedo and evapotranspiration • Competition between native tree species and indigenous species used for biomass production • Ex-situ impacts and pollution from transportation	• Habitat, food and other supporting services provided by plants
Marine energy	• Disturbance of ecosystems at construction stage (e.g. sound pollution affecting marine mammals) • Habitat loss or change due to settlements on seabed, permanent immersion of estuaries upstream of tidal energy infrastructures, change of hydrodynamic and sedimentation processes • Increased turbidity of the water column due to seabed disturbance, change in salinity, water flows more oxygenated in tidal energy infrastructures • Electromagnetic pollution by underwater cables and chemical pollution by lubricants or paintings • Change of benthic fish communities due to habitat loss • Disturbance of circulation of local and migratory species • Species mortality in tidal energy infrastructures, bird collision with offshore wind turbines and marine species collision with tidal energy infrastructures • Tropical fish mortality due to thermic shock caused by some installations • Ex situ impacts: relocation and intensification of fishing pressure out of the no-go area • Land-use change because of the cables • Pollution during extraction of rare earth oxides (new generation turbines)	• Biodiversity conservation through no-go areas for fishing or transportation activities • Shelter for some species

(continued)

Table 1 (continued)

Energy source	Potential negative effects	Potential positive effect
Geothermal energy	• Habitat loss when natural areas are converted into geothermal installations • Habitat change when the site is deforested, construction of roads and wells, and seismic surveys, affecting reproduction, feeding and migration of some species • Emission of toxic pollutants leading to plant defoliation or absorption by organisms • Noise and heat pollution	

energy found a new echo after the disaster of Fukushima in 2011. In November 2017, French Government revised its ambition to reduce nuclear power to 50% of its energy mix by 2025 (French Government 2015) to 2030 at the earliest. It is seen as a realistic shift for climate, since scenarios indicate that reducing nuclear power production to 50% by 2025 would imply emitting about twice more CO_2 than today through coal and gas energy production, to complement the production of electricity by renewables which would not be high enough (RTE 2017). Therefore, a 2030 deadline could be relevant for reducing the share of nuclear power to 50% while stabilizing CO_2 emissions. The energy mix with the lowest CO_2 emissions (9 Mt instead of 22 Mt today) could be achieved by 2035, but nuclear power would have to be maintained to 56% of energy production (RTE 2017). These findings are in line with McCombie and Jefferson (2016), who highlight that nuclear power generation has levels of GHG emissions, waste generation and resource use comparable to the ones of renewables. Brook and Bradshaw (2014) remind that when direct damage on biodiversity is to be prevented, the best options for energy production are the ones using as little resources as possible. The energy transition should therefore focus on a lower energy consumption, instead of a similar or increasing consumption of clean energy from renewable sources. Recent progress in nuclear technology and generation IV nuclear plants based on thorium could meet the global demand for non-carbon energy and thorium resources could last millions of years (Brook and Bradshaw 2014). Today, uranium is still a cheap resource but treatment of radioactive waste (by stocking or recycling) remains a major issue that needs to be solved, were nuclear power to become widely used (Brook and Bradshaw 2014). These issues add up to the negative impacts of nuclear power on biodiversity, including pollution when extracting uranium and water temperature changes in rivers because of the cooling process. When looking at the product life cycle, including extraction and transportation phases, renewables should be submitted to similar analysis as nuclear power, in terms of biodiversity and climate outcomes. Science could bring answers to those questions, and contribute to the public debate which is strongly marked by the general wariness against radiations. Despite the positive outlook nuclear power could bring on energy production and biodiversity protection, the risk of a major nuclear disaster remains unresolved.

Biodiversity Underlies the French Action Plan for Climate

Every measure aiming to decrease the demand for energy is very positive for biodiversity, while the shift from one source to another, be it renewable, is not: any kilowatt per hour that is not produced is an impact avoided on climate and on biodiversity. Biodiversity stakeholders could seize this approach to strengthen their actions further. More generally, promoting a restraint consumption in energy promotes an overall austerity regarding the consumption of other natural resources, such as meat, another major source of GHG and of land-use change (FRB 2017).

French Government released its Climate Plan in July 2017, describing how the country will implement the Paris Agreement. It contains several innovative guidelines, and most actions refer, directly or not, to biodiversity, thus making this climate policy one of the most inclusive of biodiversity issues to date (Laurans and Rankovic 2017). The seven first objectives are dedicated to energy efficiency and energy savings, including an ambitious target to renovate old buildings for thermal efficiency. Objective 15 of the Climate Plan deals with the critical challenge of decreasing imported deforestation (Henders et al. 2015) in France. Reducing imported deforestation, though often referring to the production of food commodities, would also apply for biomass imported in France for energy production.

The new French Climate Plan may contain some risks for biodiversity, mostly related to two of its objectives. Objective 11 is about reaching carbon neutrality by 2050, by limiting GHG emissions to the quantity that ecosystems on Earth are able to absorb, acting as sinks. Given the current emission trends, this measure would put a tremendous pressure on ecosystems as this thirty-three-year timeframe is very short (Laurans and Rankovic 2017). Some questions need to be addressed if this is to be achieved through afforestation: what is replaced by new forests? Which tree species are planted? Carefully planned and implemented, this carbon policy can turn to an opportunity for biodiversity, only if it promotes the protection of existing carbon-rich ecosystems. Objective 14 of the Climate Plan refers to speeding up the development of renewables, by simplifying procedures for setting up infrastructures. This reflects the well-spread idea that the development of renewables is hindered by civil society's actions resulting from a "not-in-my-backyard" behaviour (Mattmann et al. 2016), and that, for the energy transition to take place, appeal procedures must be streamlined. This measure of the Climate Plan could bear some threats to biodiversity if it prevents local non-governmental organisations to question and stop, if needed, the development of renewable energy projects in biodiversity-sensitive areas. As time goes, appeals are however less likely since developers come with more sustainable cases, and this is indeed good news since appeals reveal a failure of the consultation process. There are many tools to conduct local consultations, but they regularly fail because projects are not flexible once the format is approved. Changing the qualification, size and characteristics of projects after approval should be simplified, and there would be a lesser need to change appeal procedures (Mermet et al. 2004).

The Climate Plan is a positive development to advance biodiversity conservation in parallel with climate mitigation and adaptation. It stresses out the contributions of a rich biodiversity and functioning ecosystems to the climate change fight. However, it could go further in thinking forward the impacts, negative and positive, that some climate policies, including the development of renewables, might have on biodiversity.

Mitigating the Impacts of Renewables on Biodiversity for an Ecological Transition

So far, renewables have been promoted all as one, but this paper illustrates the variety of impacts that different infrastructures relying on different power sources may have on biodiversity. Renewables should be prioritized, taking into account their efficiency and impacts (Laurans and Rankovic 2017). Biodiversity stakeholders should participate in this prioritization process, which would be led by the stakeholders of each energy branch otherwise, with the risk for biodiversity and water-related issues to be overlooked. More generally, biodiversity research should better address energy-related issues and biodiversity stakeholders should be more active in platforms dealing with biodiversity and energy, such as the Strategic Environmental Assessments of the Plurennial Programme for Energy or the Regional Schemes for Climate, Air and Energy. The decentralization implied by the energy transition sets it in a local ground which requires a systemic approach of the territory and energy issues (Trommetter 2017).

All participants to the event led by FRB on reconciling energy transition with biodiversity preservation agreed on one obvious but primordial solution: to settle renewable energy infrastructures in biodiversity-poor areas (FRB 2017). The other major point is to focus efforts on biodiversity mainstreaming in all sectors, including energy, as countries committed at the 13th Conference of Parties of the Convention on Biological Diversity in 2016 (CBD 2016). This can be done for example by developing biodiversity indicators for the energy transition, rather than looking only at carbon emissions. This would necessarily make the picture more complex, but it is nevertheless essential not to face unexpected and irreversible feedback throughout the biosphere. These two guiding principles should then be complemented by a number of approaches which were discussed at the conference organised by FRB and are presented below.

Spatial Planning

Renewable infrastructure would have lesser impacts on biodiversity if located far enough from protected areas (Marx 2017). Local studies are key to identify occurring species, their ecology and behaviour, which will in turn help understand the potential impacts of the infrastructure depending on its location or the time of year (e.g. during the migration period, about 60% of birds killed by wind turbines are sparrows, but the species most vulnerable to turbines are birds of prey with very low numbers of individuals). A recent study from the French League for the Protection of Birds (LPO) reveals that twice more remains of birds are found by wind turbines settled within or nearby Natura 2000 protected areas than other turbines, and that the birds killed are much more often listed on the IUCN Red List of Endangered Species or on the European Union Bird Directive (Marx 2017). The most lethal wind turbines are often the older and smaller ones, which were built before the Natura 2000 network was completed and at a time when environmental legislation was weaker. Major energy companies shared their experience on spatial planning during the conference, explaining that when biodiversity issues are factored early in the project design and budget process, they can be addressed more easily: through a small change of location (e.g. the reorientation of the methane terminal of Dunkirk by EDF) or the addition of specific device (e.g. coloured disks on power lines to increase their visibility for birds). However, LPO observed that as for wind turbines, none of the existing devices such as on/off functions controlled by cameras are efficient enough to remove the threat on birds, and that, for all kind of renewables, only avoidance of key biodiversity areas through spatial planning and ecological knowledge is a viable solution to prevent negative impacts on biodiversity (FRB 2017).

When this is not possible to mitigate impacts, offsetting must be undertaken (French Government 2016). For example the company Engie creates hedge ecosystems to compensate the destruction of natural areas for the settlement of its infrastructure. This is in line with the "Avoid Reduce Offset" triumvirate officialised by the law on biodiversity of 2016, which is key to protect and restore biodiversity (Trommetter 2017).

Guidance and Monitoring

In order to minimize the impact of renewable energy infrastructure, such as wind turbines, on biodiversity, French operators have to monitor and report bat mortality to the Muséum National d'Histoire Naturelle on a yearly basis. However, submission rate is less than 5%, and data is heterogeneous due to a lack of harmonization of methods and metadata (FRB 2017). Monitoring is crucial to assess the adequacy of guidance and policies for mitigating biodiversity impacts: the European Union provides guidance for wind turbines to be set up 200 m away from woods or hedges, but research has shown that they should be at least 1000 m away for species not to suffer sublethal effects. It is estimated that 2400 km of hedges became unsuitable for bat habitat in Brittany and Loire regions due to the avoidance of wind turbines by the bats (Coly et al. 2017). Enforcement of recommendations is also an issue, for it is estimated that about 90% of wind turbines in France do not follow them. Monitoring through citizen science, like the US eBird platform, may be very helpful to provide data to assess the potential impacts of infrastructure such as wind turbines, and have proved useful to make cases for relocation when it threatened protected species such as bald and golden eagles (Sullivan et al. 2017). Civil society can also support the process, such as LPO who launched a large programme to assess the impacts of wind-turbines on birds and develop solutions to reduce them (Trommetter 2017).

Engineering

One of the main difficulty in introducing biodiversity concern into decision making process is to assess the reality of the impacts. Product life cycle analysis (LCA) could become a key tool to understand a broad range of the impacts renewable infrastructure may have, during all phases, and to develop solutions to avoid or mitigate negative impacts. LCA can look at land-use change impacts by taxa, taking also into account species endemism and vulnerability, based on IUCN data. The indicators of potential species loss and potentially disappeared fraction of species are useful in that regard, but sensitivity of ecosystems, ecosystem fragmentation, local impacts and differences of practice on the ground and genetic diversity are not yet addressed in LCAs (UNEP 2016a). At the current stage, LCAs help raise developers' awareness of key biodiversity issues, but the picture remains general. Research is therefore focusing on conceptualizing and operationalizing biodiversity into LCA. For example, LCAs could cover the five drivers of biodiversity loss identified in the *Millenium Ecosystem Assessment*: while climate change, habitat change and pollution are factored in, invasive alien species and overexploitation are not. Such new approaches have not been used yet on renewable energy infrastructure (Verones et al. 2015).

Mobilizing Research

On top of the impact assessments of infrastructure for renewable energy, science has also a key role to play to assess the impact of energy policies, at the European and national level. For example, a large field open for research is the viability of an energy strategy relying on biomass. Biomass is a standalone source of energy since it is renewable only if the regeneration rate is higher than removal within a specific timeframe (Trommetter 2017). Therefore, more research is needed on the key features of forest biodiversity in order to fully understand the effects that exploitation of biomass would have on French forests, including the relationship between tree age and biodiversity, the importance of dead wood, and biodiversity variations across forest layers. Forest research could thus help improve the biodiversity potential of forest plantations for biomass exploitation, to avoid large, biodiversity-poor monocultures without undergrowth. However, the possibility for biomass-energy exploitation to remain within safe limits for biodiversity preservation will mostly depend on the scale of operation. Davi et al. (in prep.) studied the resilience of the social-ecological system around the biomass plant in Gardanne, Provence, which is the largest plant producing energy from wood in France. They identified current biomass production levels in the plant's wood-supply area, assessed the future production trends, evaluated existing ecosystem services and developed indicators on the status of the forest, while factoring in land property. Using a method of reverse engineering, they found that the plant would need 855,000 tons of wood by 2025, coming from a 400 km radius, in order to be fully operational. This is twice more than the current volume of wood exploited in the administrative region of Provence-Alpes-Côte d'Azur. The study shows that despite increasing forest area in France, current unexploited parcels are difficult to access; it is therefore likely that pressure intensifies in currently exploited areas. Other factors such as climate change reinforce the vulnerability of the Mediterranean forest and should be taken into account when assessing the potential impacts of Gardanne plant. In this case, research helped mapping all stakeholders and supported consultation about the project, which was essential for minimizing the impacts of the plant on local biodiversity and quality of life, and for social acceptation.

Social sciences are crucial to understand the mechanisms of social acceptation of the renewable technologies, the share of biodiversity that societies would accept to give up, and how to increase awareness and trainings on issues closely interlinked such as climate change and biodiversity, including in the field of energy. Humans are also to be studied as part of the socio-ecosystems, with their efforts to maintain the resilience of this system through both biodiversity preservation and climate change mitigation (Trommetter 2017).

Scenarios and Models

Scenarios and models, calling on multiple research disciplines, can play a major role to explore the potential effects that energy policies may have on biodiversity. For example, models combining environmental and economic variables show that biomass, for biofuel or electricity production, is not as good for the environment as first thought, because of the overexploitation of forests and land-use change it may induce (Valin et al. 2015). Harvesting very often results in a reduction of biological and spatial diversity which weakens the forest ecosystem and the local biodiversity dynamics (Trommetter 2017). Specific impacts on biodiversity are difficult to model through proxies such as carbon richness, widely used in climate models, because of the specificities of local contexts. Research has therefore been developing biodiversity indicators by combining landscape cover and land-use intensity with biodiversity richness. The resulting indexes are a progress towards the integration of biodiversity variables into the models, but they still lack key information to assess habitat fragmentation, populations dynamics, interactions within ecosystems, changes in genetic diversity etc. There is still progress to do to better understand the impacts of meeting the global objectives of carbon emission reductions. Models show that in order to limit global warming to 2 °C, land conversion for biomass production on one hand and the necessary carbon sinks on the other hand would imply that about 500 million hectares would be dedicated to agriculture for biomass (Havlík et al. 2015). The unavoidable ex situ biodiversity issues of one area being the in situ issues of the other, the question is whether one can be virtuous at home with a behavior harmful elsewhere (Trommetter 2017): the impacts on biodiversity, especially in developing countries where the large majority of land would be available for conversion, need to be particularly reflected upon.

Beyond studying future impacts and guiding policy development, scenarios and models can also be used for decision-making, for example through serious games which help stakeholders to step into each other's shoes and understand each other's key motivations. Such activities raise stakeholders' awareness on the multiple aspects that are to be taken into account to meet different, sometimes opposing, objectives (e.g. biodiversity conservation vs resource exploitation) (Garcia and Speelman 2017). Modelling is also used to assess the resilience of social-ecological systems through the description of an area, its resources, stakeholders, institutions and issues, and alternative system developments showing whether the system is becoming more or less resilient (Resilience Alliance 2010). This was applied for example by Davi et al. (in prep.) to identify the potential impacts of the operation of the biomass plant in Gardanne.

EU Countries Should Inspire the World for a More Cautious, Time-Taking Energy Transition for the Sake of Biodiversity

The main observation from scientific literature and the feedback of energy stakeholders is that the push for renewables has led to a frantic development of the sector, with an ex post realization of the negative impacts it induces when not thought through. An illustrative case being the promotion at the European Union level of biomass energy, which lead to the unexpected large importation of wood from the US and from Canada which was unsustainably harvested (European Commission 2015). The energy transition should be operated at a slower pace to allow science to catch up with it, and an energy mix based on renewables, fossil fuel and nuclear power could allow to keep meeting energy demand while going for a wise zero-carbon energy production. On top of the impact assessments of infrastructures for renewable energy, science has also a key role to play to assess the impact of energy policies, such as the European policy promoting biomass energy that may have indirect impacts beyond the current players, as highlighted by Gazull in FRB 2017 and in Cuypers et al. 2013.

Indeed, the EU is often looked up to by the world, and its endorsement of biomass energy turns it into a good, clean, innovative source of energy that may provide an incentive for many developing countries to strengthen the exploitation of their forests for energy production, which is one of the main drivers of deforestation around urban areas in the global South. To sum up, the energy transition whose use is local, but whose resources and deployment are global, must be considered globally (in situ and ex situ) when being assessed (Trommetter 2017).

Conclusion

Policy sectors such as energy and environment are dealt with independently in politics and by stakeholders. Each stakeholder is therefore advancing its own policies to achieve its own objectives, ignoring the fact that some of these may be detrimental to other policies and targets, or even counterproductive for their own objective since many issues influence each other. When looking at the impact of the energy transition on biodiversity, it is observed that the question is hardly ever asked, be it in the policy, research or operational area. A few scattered studies analysed the potential or actual impacts of energy infrastructures on biodiversity, but these impacts need to be better factored in by stakeholders of the renewable energy sector, by asking: "what may my impacts be when it comes to biodiversity?". This demand would in turn boost research on the topic, including the development of solutions to mitigate or offset the impact of renewable energy infrastructure. Research can also support decision-makers in better anticipating the effects of energy policies and measures on biodiversity, using tools such as scenarios and models. Recent climate policy development in France gave a positive signal for all stakeholders to better acknowledge and work on the synergies between climate and biodiversity. While the energy transition addresses the urgent need for climate change mitigation and aims to reduce CO_2 emissions, literature increasingly documents examples of offsetting (rebalancing emissions to zero) or even a net removal of CO_2 through biodiversity protection. The international research initiative 4‰ aims to identify farming practices promoting carbon storage in agricultural land so that it offsets part of human CO_2 emissions. A territorial and systemic approach is essential to overcome such challenges. Currently, it is mostly on the scale of territories that the issues of sustainable development, including the implementation of renewable energies, their side-effects, and the erosion of biodiversity, are perceived and it is probably also there that both fair and democratic solutions can be found. Policy emphasis on such measures would help rebalance biodiversity versus climate objectives, highlighting the interlinkages between both issues.

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Approaches to Ecosystem Services and Biodiversity Assessment in Belarus

Siarhei Zenchanka and Nikolai Gorbatchev

Abstract ***Purpose***—Sustainable economic development requires consideration of economic, social and environmental factors. Since the last decade of the twentieth century, there has been a demand for statistical data reflecting the state of the natural environment and the impact on it of human society. At the same time, statistics are required that reflect the impact of ecosystems on the economy. Due to human activities there is an increasing uncertainty about the amount of environmental assets that are currently available in any country. The goal of the work is to consider the world trends in the definition of ecosystem services, their evaluation and accounting, and implementation of ecosystem services in the Republic of Belarus. ***Design/methodology/approach***—Descriptions of trends related to quantifying the natural resources in EC countries and worldwide are provided. Comparative study of Belarus approaches to implementation of the best ecological practices was developed. ***Findings***—Belarus has some unique practices in the field of ecosystem services management, which also may be analyzed and disseminated as good practices of ecosystem accounting and management, including forest resources management related with wild medical plants, berries and mushrooms, as well as cultivation of lands contaminated with radionuclides after Chernobyl disaster and monitoring of radioactive contamination and biodiversity, especially related with cross-boarder contamination between Belarus, Russia and Ukraine. ***Originality/value***—The comprehensive analysis of modern tendencies in natural capital and ecosystem services assessment and biodiversity was suggested.

Paper type—Research paper.

S. Zenchanka · N. Gorbatchev (✉)
Minsk Branch of Plekhanov, Russian University of Economics, 127/2 Mayakovskogo Str., 220028 Minsk, Belarus
e-mail: ngorbachev@tut.by

S. Zenchanka
e-mail: zench@tut.by

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Introduction

Sustainable economic development requires consideration of economic, social and environmental factors. Since the last decade of the twentieth century, there has been a demand for statistical data reflecting the state of the natural environment and the impact on it of human society. At the same time, statistics are required that reflect the impact of ecosystems on the economy.

Agenda 21 (1992), adopted by the United Nations Conference on Environment and Development in Rio de Janeiro, considers "Integrating Environment and Development in the Decision-Making Process" (Chapter "Implications for Biodiversity of Potentially Committed Global Climate Change (from Science and Policy)") and "Conservation and rational use of resources for development" (Section "Natural Capital and Ecosystem Services: International Approach") as the main development priorities.

Costanza and Daley (1992) considered the concept of "natural capital", which includes "renewable or active natural capital" and "non-renewable or inactive natural capital". At the same time, renewable capital is restored by solar energy. Ecosystems in this work relate to renewable natural capital. They can produce ecosystem products, such as wood, and also provide ecosystem services, for example, carbon dioxide absorption. Examples of non-renewable capital are fossil fuels and mineral resources.

The ecosystem is defined as a dynamic complex of plant, animal and microorganism communities and non-living environment interacting as a functional unit (Millennium 2003) and as the benefits that a person derives from ecosystems. Humans are an integral part of ecosystems.

The goal of the work is to consider the world trends in the definition of ecosystem services, their evaluation and accounting, and implementation of ecosystem services in the Republic of Belarus.

The practical importance of the work lies in the analysis of the world trends and policies of the European Union in the development of ecosystem services. It is shown that Belarus has some unique practices in the field of ecosystem services management, which also may be analyzed and disseminated as best practices of ecosystem accounting and management.

Natural Capital and Ecosystem Services: International Approach

Natural Capital is considered as "the environmental stock or resources of Earth that provide goods, flows and ecological services required to support life. Examples of natural capital include: minerals; water; waste assimilation; carbon dioxide absorption; arable land; habitat; fossil fuels; erosion control; recreation; visual amenity; biodiversity; temperature regulation and oxygen. Natural capital has financial value as the use of natural capital drives many businesses" http://www.gdrc.org/sustdev/concepts/26-nat-capital.html. This defines the needs in natural capital accounting.

The first version of the System of Environmental and Economic Accounting (SEEA) was presented in 1993 (United Nations 1993). In 2000, the SEEA manual was published (United Nations 2000), providing practical recommendations for the implementation of SEEA modules with maximum consistency with national statistical standards.

In 2005, the report "Millennium Ecosystem Assessment" (Millennium 2005) was published, the results of which indicate that over the past 50 years, human activities have led to a huge loss of biodiversity and a decline in the volume of ecosystem services. As noted in the proof, this will have a negative impact on the development processes in all countries, especially in developing countries.

The SEEA-2003 report (United Nations 2003) gave a consistent analysis of the contribution of the environment to the economy and the impact of the economy on the environment, the composition and functions of natural capital were examined. The report was the basis for the further development of the standard on accounting for natural capital and ecosystem services.

Figure 1 shows an approximate structure of natural capital.

As it is shown in Fig. 1, in the structure of natural capital the natural resources and ecosystems are allocated. First of all the natural capital includes non-renewable and renewable capitals. Non-renewable capital consists of fossil fuels and mineral resources which humanity consumes only changing the energy balance of the Earth. Greenhouse gas emissions accompanying the process of consumption of non-renewable resources also lead to a change in the energy balance of the Planet.

Renewable natural capital forms a different type of ecosystems which produce ecosystem products and services. Renewable capital is restored by solar energy, but there is a global trend towards deterioration in the quality of natural capital and even a decrease in its quantity.

It should be noted that the link between non-renewable resources and the ecosystem is necessary, since resources are part of ecosystems and their production in many

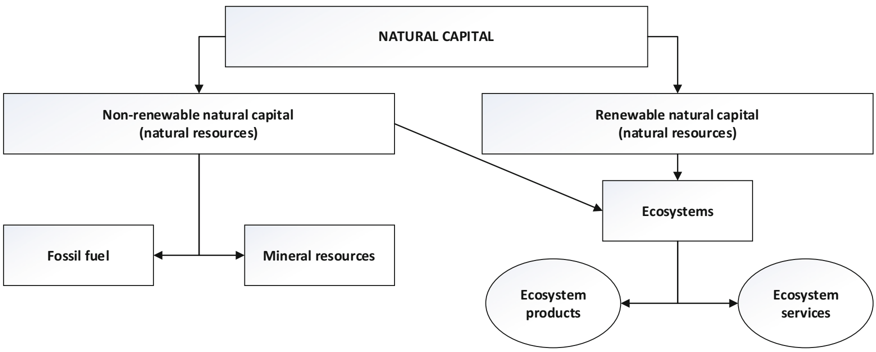

Fig. 1 Approximate structure of natural capital

cases leads to ecosystem disruption. For example, open mining of minerals not only changes the landscape, but also leads to disruption of underground aquifers.

The idea of natural capital structuring and accounting was initiated in the 1980s. However, it was generally adopted into above-like scheme in 2012: the UN Statistical Committee approved the SEEA Central Framework (2012) as an international standard for environmental and economic accounting. In addition, guidelines have been issued on the experimental recording of ecosystems (SEEA 2014), SEEA Water Accounting (2012), SEEA Energy Accounting (2012) and SEEA accounting in agriculture, forestry and fisheries (SEEA AFF 2014). The system is based on the integration of environmental and economic indicators. Internationally agreed definitions and classifications (renewable and non-renewable resources, ecosystems, etc.) are connected with corresponding statistical indicators. Ecosystem products' and services' indicators provide analysis of specific resources sectors, such as water, fisheries, land, agriculture. The motivation for structuring the natural capital results from a variety of emerging demands for integration information on environmental sustainability and human well-being.

The main types of ecosystems and ecosystem services were considered in "Ecosystems and human well-being: a framework for assessment" (Millennium 2003) and by Haines-Young and Potschin (2013):

- ***Providing services***—products that people get from ecosystems. These include cropping, livestock and game animals, seafood, food from wild plants and animals; drinking water, water used for irrigation and industrial consumption; plants that are sources for the creation of biopharmaceuticals, building materials and biomass used as a source of renewable energy. Products can be obtained from sustainably managed ecosystems, such as agriculture, aquaculture, forest plantations, natural and semi-natural ecosystems (hunting, fishing, gathering wild plants and beards);
- ***Regulatory services***—benefits derived from self-regulation of ecosystem processes (conservation of ecosystem assimilation capacity)—biogenic nutrient cycling, climate control, reduction of the negative consequences of natural disasters, pollination;
- ***Cultural services***—cultural, educational and spiritual benefits received by people from ecosystems—visiting cultural, historical, spiritual and religious places; opportunities for recreation, for example, recreation, sports, hunting, fishing, ecotourism; education and research;
- ***Supporting services***—the natural processes necessary to maintain other ecosystem services, such as soil formation.

In April 2012, following the intergovernmental negotiations, which lasted several years and were convened under the auspices of UNEP, an Intergovernmental Science and Policy Platform on Biodiversity and Ecosystem Services (IPBES) was founded (http://www.ipbes.net/about-us). The mission of IPBES is to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development (IPBES 2016).

The UNEP Ecosystem Economics and Biodiversity Initiative (TEEB) has undertaken a series of studies that highlight the importance of ecosystem services and the need for assessments. The results of these studies are presented in the Guidelines for Countries on the Economics of Ecosystems and Biodiversity (TEEB 2013). "The Economics of Ecosystems and Biodiversity" is an international initiative aimed at drawing attention to the benefits of biodiversity, covering ecosystems, species and genes. This initiative covers existing data to emphasize the value of biodiversity and ecosystem services, the increasing costs of biodiversity loss and ecosystem degradation and the benefits of overcoming these problems.

There are eleven proposals in this Guideline directed to reducing biodiversity losses economically (TEEB 2013):

1. Make the values of nature visible, for example, by assessing the role of biodiversity and ecosystem services and their impact on the economy and society;
2. Provide the assess to the value of ecosystem services and integrate them into the decision-making process to improve the evidence base for decision-making;
3. Take risks and uncertainties into account, for example, by understanding and applying minimum safety standards or principles of prevention;
4. Provide the future for sufficiently long periods of time to take into account the needs of future generations and evaluate the cost and benefits of decisions and policies using different discount rates;
5. To manage better, i.e. invest in improving indicators of biodiversity and ecosystem services, in mapping ecosystems, and in integrating indicators into national accounts that take into account the roles and values of nature;
6. Work with natural resources to reduce poverty, identify synergies between nature, livelihoods and well-being, and target investments in public goods. Human dependence on ecosystem services and, in particular, their role as a life-saving circle for many poor households, should be fully integrated into policies, strategies and implementations;
7. Encourage the disclosure of corporate information to compensate for adverse effects that cannot be avoided, to ensure that there is no "net loss", including through a natural form of compensation, achieving a net positive effect;
8. Change incentives through market reforms (subsidies, pricing, taxes, fees and penalties), property rights, liability, intellectual property rights and other measures that can make supply chains more "green", encourage private investment in the development and Sustainable use;
9. Identify protected areas, manage and invest in protected areas to ensure a comprehensive, representative and efficient network managed on an equitable basis. Protected areas are a certain monetary value;
10. Invest in environmental infrastructure to support mitigation and adaptation to climate change, water security and other policy objectives;
11. Introduce the issues of the economy of nature in various ministries, sectors and relevant policies, i.e. in an economy and finance, trade and development, transport, energy and mining, agriculture, forestry, planning, etc.

The above recommendations fully correspond to the trends in the development of the world economy.

"Green" and "Circular" Economies Concepts

The concept of a "green" economy was proposed more than 20 years ago (Pearce et al. 1989) and became widespread in the 21st century. In 2007, they submitted a report "Blueprint for a Green Economy" to the Shadow Cabinet (https://www.researchgate.net/publication/39015804_Blueprint_for_a_Green_Economy).

In 2008, the UN, in collaboration with many stakeholders, announced the "Green Economy Initiative" (http://www.greeneconomycoalition.org/content/un-environment-programmeE99s-greeni-economy-initiative) which consists of several components aimed at analyzing and politically supporting investments in "green" sectors of the economy and involving other sectors in this process. Green Economy Report (UNEP 2011) considered investing in natural capital and investing in energy and resource efficiency and it has found that a "green" economy values and invests in natural capital. Report (UNEP 2015) considers the investment in ecosystem restoration and rebuilding of natural capital as an essential part of investments in environmental sustainability. This report suggests "to adopt the valuation of natural capital in national accounts and development indexes, as it enables a country to develop a sense of its "true wealth"; and value the natural capital degraded or used up in economic processes, as it provides a measure of "true income"".

The final document of the Rio + 20 Conference "The future we want" emphasizes that the "green" economy should improve the ability to rationally use natural resources with less environmental impact, improve resource efficiency and reduce waste (Report 2012).

Key sectors of the "green" economy, such as agriculture, energy, fisheries and forestry, waste, water use, etc., are directly related to the receipt of ecosystem services.

The development of the "green" economy led to the development of a "circular" economy, which received priority in making promising decisions to achieve economic development in the presence of environmental constraints. In the European Union, this was reflected in the 7th Environmental Action Program, which aims to protect, preserve and strengthen the natural capital of the European Union. It also sets goals for the development of a low-carbon, resource-efficient and "green" economy. The program assumes that the global eco-industrial market will double in the next 10 years, and the European renewable energy sector will create more than 400,000 jobs by 2020 (Programme 2014). In addition, European countries increasingly view the circular economy as a political priority.

A "circular" economy is a continuous positive development cycle that preserves and enhances natural capital, optimizes the profitability of resources, and minimizes systemic risks by managing finite stocks and renewable flows.

The Report of the European Environmental Agency (EEA 2016) notes that, with an existing population of the Earth of 7.2 billion people, some planetary boundaries defining areas of safe living have already been violated. This refers to the integrity of the biosphere, the cycles of nitrogen and phosphorus, climate change, changes in soil cover, etc.

The "Sustainable Development Goals 2030", adopted in September 2015 (Agenda 2015), noted that "We are determined to protect the planet from degradation, including through the introduction of rational consumption and production patterns, the rational use of its natural resources and the adoption of urgent measures in connection with climate change, so that the planet can meet the needs of this and future generations". Many of the 17 sustainable development goals are aimed at conserving natural capital and using ecosystem services.

Methods and Limitations

The investigation is based on analyzing the legislative base of the Republic of Belarus, their comparison with international ones, analyzing of National strategies and programs, scientific reports and articles.

The article must give an answer on next questions:

1. What ecosystem services are presented in Belarus?
2. Which legislation governs ecosystem services in Belarus?
3. What biodiversity measures have been taken?

Ecosystem Services in Belarus

Providing Services

Crop. Agriculture of Belarus is specialized in cultivating traditional for moderate breadth of cultures. In the structure of plant growing a high proportion is occupied by grain and leguminous crops, as well as forage crops, which is due to the specialization of the republic's agriculture, mainly in dairy and meat cattle breeding. The main crops are barley, rye, triticale. A special place is occupied by potatoes and flax. The main vegetable crops are carrots, beets, cabbage. In Belarus, about 16% of the world's flax is concentrated, or more than 20% of its crops of the European continent (Belagro 2016; Digest 2016).

Livestock and game animals. In animal husbandry, mainly cattle are grown for the production of milk and meat, as well as pigs and poultry (Belagro 2016; Digest 2016).

Fish. Commercial fishing in inland waters is one of the directions of the fishing industry in Belarus. River fishing is concentrated mainly in the southern regions, where the rivers Dnipro, Pripyat, Sozh, Berezina and their tributaries are being developed. The fishing value Neman river is much lower, r. Western Dvina for commercial fishing is practically not used.

About 56 species of fish live in water bodies and rivers of Belarus but no more than 20 fish species have definite commercial importance. Analysis of the statistical data of commercial catch from lakes, rivers and reservoirs over the past five years has shown that about 75% of catches fall on three species—roach, bream and carp. Seafood accounts for no more than 0.2%, eel—1.9%, large predators—ichthyophagous (pike, catfish, pike perch, asp)—4.4%.

With the adoption of the lease law, fishing grounds were transferred to numerous tenants from state and non-state enterprises and individuals. This led to an increase in the number of water bodies and streams used for fishing. Currently, 281 tenants (including state fisheries) are exploiting for the purpose of fishing about 600 lakes and reservoirs, a total area of 1.2 thousand km^2 and 2.1 thousand km of rivers (Belagro 2016).

Water. Renewable freshwater resources of the Republic of Belarus are represented by river runoff and groundwater, the volume of which is formed in natural conditions due to precipitation on the territory of the country (internal runoff), as well as the inflow of river and groundwater from adjacent countries. The total annual flow of rivers is determined on the basis of measurement of water levels and discharge.

The natural resource of fresh groundwater is the total flow of groundwater flow, which is provided by infiltration of atmospheric precipitation. The magnitude of the infiltration feeding of aquifers in the zone of active water exchange is 10–20% of the average long-term value of atmospheric precipitation. In the general runoff of the rivers of Belarus, the share of groundwater is 27%.

The main source of surface water resources of the country are medium and large rivers, the volume of water flow by which in average water years, as a rule, does not exceed 57,900 million cubic meters per year. During the high water years, the total river runoff increases to 92,400 million cubic meters per year, and in low-water (95% of the supply) it is reduced to 37,200 million cubic meters per year. At the same time, the rivers of the Black Sea Basin account for 55% of the total annual flow, the Baltic Sea basin—45% (Report 2016).

Belarus ranks fourth in terms of water resources of rivers in Europe after Norway (376,000 million cubic meters per year), UK (152,000 million cubic meters per year) and Poland (85,400 million cubic meters per year). The natural resources of fresh groundwater are 15,900 million cubic meters per year, and the forecasted resources are 18,100 million cubic meters per year.

Wastewater treatment. The ecosystem function for assimilating water pollution and waste processing is being regulated. Belarusian Research Center "Ecology" developed a technical code of good practice "Environmental Protection and Nature Management. Procedure for Conducting a Valuation of Ecosystem Services and Determining the Value of Biodiversity". The proposed methods allow estimating the value of forest, marsh and meadow ecosystems and the cost of corresponding ecosystem services on their basis (Code 2012).

Timber. Forests and forest resources of the Republic of Belarus are the most important element of the national wealth of the country, which have a significant impact on its sustainable social and economic development. If the Republic of Belarus occupies the 13th place in the Europe, according to the area of land resources per capita, on such characteristics as the forest cover of the territory, the forest area and the stock of growing timber per capita, our country is included in the first ten forest states of the Europe. The average age of the Belarusian forests, which forms the forest fund of the country, is 54 years. According to experts' estimates in 2015, the timber reserves in our country amounted to 1714.3 million cubic meters, which is equal to the total reserves of Great Britain, Hungary and Italy combined (Belagro 2016).

The forest gives valuable birch sap, gill, game and furs, and the integrated use of forest resources, including processing of such wastes as stumps, roots, bark, small and low-grade wood raw materials, obtained from the crown and during cutting, and technical greens, allow produce dozens of valuable products.

The Republic of Belarus has a rich potential of low-value wood raw materials and waste that can be used as boiler-furnace fuel. The development of small-scale energy based on the use of wood fuel is one of the most important directions, ensuring a reduction in the share of imported energy resources, raising the level of energy security of the country.

Wild medicinal plants. In addition to tree stocks, forest resources also include non-wood forest products, which are represented by berries, fruits and mushrooms (wild plants). In the Belarusian forests, there are over 140 species and forms of edible mushrooms, and the possible volumes of wild berry production reach up to 200 thousand tons.

Currently, almost half of the domestic medicines are made from plant materials, including those grown in the forest. A large number of forest plants-honey-plants are a solid fodder base for beekeeping (Report 2016).

Land and soil. Land resources include all types of land: agricultural, human settlements, industry, transport, resorts, reserves, state forest fund. The land fund of the Republic of Belarus remains unchanged and at the beginning of 2016 it is 207.60 thousand hectares. Agricultural lands occupy 41.3% (8581.9 thousand hectares), forest lands—8742.1 thousand hectares (42.1% of the total area).

As a result of the Chernobyl disaster, 23% of the territory of Belarus were contaminated with radioactive pollutions, on which there were 3678 settlements. The most affected territories of the Brest, Gomel and Mogilev regions. A quarter of the country's forest fund has been subjected to radioactive contamination in Belarus (Chernobyl 2017).

A special authority, Department for Elimination of the Consequences of the Chernobyl Disaster subordinated to the Ministry of Emergency Situations of the Republic of Belarus, is responsible for rehabilitation of lands, forests, water bodies and provision of safe living conditions for people in areas contaminated by radionuclides Report (2016). Programme (2010).

Regulatory Services

Climate change. In Belarus, as in the whole world, climate change mainly related to global processes. However, its share in the world budget of carbon emissions is less than 0.01% (Contributions 2015). During the period of 1995–2005 on average 1.6% of the GDP was spent on improving energy efficiency with increasing to 3.4% of the GDP in 2006–2010, and up to 5% of GDP in 2011–2015. However, the following climate change facts that influx on ecosystem services are registered in Belarus:

– Reducing the yield of traditional crops and growing new crops;
– Climatic zone displacement;
– Migrating animals, birds and insects;
– Drying of forests, increase in fire hazard in forests;
– Reducing the harvest of mushrooms and berries;
– Unfavorable and dangerous hydro meteorological phenomena;
– Increased growth of parasitic and infectious diseases, allergies;
– The emergence of climate migrants due to famine and natural disasters.

For the second period of the obligations of the Kyoto Protocol, the Republic of Belarus has undertaken a number of voluntary commitments to reduce energy intensity of GDP and greenhouse gas emissions with target indicators up to 2020, which are reflected in the main program documents and normative legal acts of the Republic of Belarus (Contributions 2015):

– The target for reducing greenhouse gas emissions in 2020 by 8% to the level of 1990;
– Ensuring greenhouse gas emissions by 2020 at the level of not more than 110 million tons.

Ecosystem effects of Chernobyl disaster. Formation of radioactive contamination of the natural environment in the territory of Belarus began immediately after the explosion of the reactor. The peculiarities of meteorological conditions in the period April 26-May 10, 1986, as well as the composition and dynamics of the accidental release of radioactive substances, caused the complex nature of the contamination of the territory of the republic.

Analysis of radioactive contamination of Europe with cesium-137 shows that about 35% of the Chernobyl fallout of this radionuclide on the European continent was located on the territory of Belarus. The contamination of the territory of Belarus with cesium-137 with a density of over 37 kBq/m^2 accounted for 23% of the total area of Belarus (for Ukraine—5%, Russia—0.6%).

Surface water is the main factor that determines the migration of radionuclides in ecosystems. Especially important is the assessment of the transitional role of rivers, which are the main carriers of radionuclides and contribute, among other things, to their transboundary movement. The problem of radioactive contamination of air masses remains relevant in the areas adjacent to the resettlement zone. It is determined by the content of radioactive dust in the surface layer of the atmosphere.

Dust formation significantly increases during agricultural and other works with an active technogenic impact on the soil. On radioactive contamination of surface air, a significant local influence is exerted by certain natural phenomena, primarily forest and peat fires.

The vegetation of the territories of radioactive contamination forms the basis of the fodder base of wild animals, in which there is an increased content of radionuclides accumulating in muscle tissue and bones. Hunting and commercial ungulates show a clearly expressed seasonal dependence of accumulation of radionuclides (increase in the summer-autumn period). The composition and structure of zoocenoses undergoes significant changes in the zones of alienation and resettlement. Currently, the ecosystem development of contaminated areas is carried out mainly at the expense of public funds (Chernobyl 2017).

Cultural Services

There are 2 national nature reserves, 4 national parks and 85 local nature reserves on the territory of the Republic of Belarus. Specially protected natural areas to ensure the preservation of the natural balance, the genetic fund and serve as centers for the reproduction of plants and animals, combined with limited and consistent use of other natural resources. About 80% of rare and endangered wild plants and about 90% of rare and endangered wild animals live within the boundaries of specially protected natural areas. The conservation of rare and endangered species of wild animals and wild plants is possible only with the protection of their habitat, taking into account climatic, geophysical and other conditions. A special role is played by the preservation of the environment-forming species of wild animals and wild plants that form the internal environment of the ecological system. Formation of an optimal system of specially protected natural areas of the Republic of Belarus is aimed at preserving natural ecological systems, biological and landscape diversity, ensuring ecological balance of natural systems and sustainable use of animal and plant, natural territories (National Strategy 2014).

Ecotourism is widely spread in Belarus. Tourists are offered routes to such natural complexes as Belovezhskaya Pushcha, Berezinsky Biosphere Reserve, Pripyatsky Reserve and others.

A key tourist attraction of Belarus, Belovezhskaya Pushcha National Park, is what's left of the primeval forest which used to stretch from the Baltic Sea to the Bug River and from Odder to the Dnieper River. Belovezhskaya Pushcha National Park was made a UNESCO World Heritage Site in 1992. In 1993 it was granted UNESCO Biosphere Reserve status (http://www.belarus.by/en/travel/belarus-life/belovezhskaya-pushcha). The park is famous for its ancient named oak trees dating back more than 500 years. In all there are almost 900 species of trees and flowers. It is also home to more than 250 animal and bird species. The Belovezhskaya Pushcha National Park also boasts a zoo, library and a museum, and supports wood processing, handicrafts and various local industries.

The Berezinsky Biosphere Reserve is the oldest and the only natural area of protection in the Republic of Belarus of the highest rank. It is a real model of the natural environment, one of very few undisturbed corners of European part of the southern taiga (http://www.berezinsky.by/en/ecotourism/routes/pedestrian/). This reserve suggests such routes as “Trail of discovery” (interactive excursion with many ecological games, “Along the forest wildlife path” (ecological track) and “Kamennaya Plita” (Stone Plate).

Pripyatsky Park, one of the national parks of Belarus, is located between the rivers Pripyat, Stviga and Ubort. Special protection has been granted to about 190,000 ha with more than a third represented as a wildlife reserve (http://www.belarus.by/en/about-belarus/natural-history/pripyatsky-national-park). At present the National Park Pripyatsky is one of the most popular tourist attractions in Belarus. The national park is home to 51 species of mammals: wild boar, deer, elk, doe, hare, fox, muskrat, raccoon dog, beaver, etc., including rare species: European bisons, European mink, European lynx, badger, garden dormouse, common dormouse, hazel dormouse. The National Park Pripyatsky has the international status of the key ornithological territory. It is home to 256 species of birds (79% of all the birds in Belarus), including 65 species in the Red Book of Belarus.

Supporting Services

In Belarus, biodiversity depends on the state of natural ecosystems, which occupy about 50% of the country’s territory. These are mostly forested, and their condition is the most sustainable. To conserve forest ecosystems, there is enough protection and sustainable use. A strategy for adapting forestry to climate change by 2030 has also been developed.

Wetlands are another significant biosystem in Belarus. They occupy a smaller area, they are less sustainable. Now the wetland complexes occupy 863,000 ha, there are more than 40% of the Red Book species of birds. In Belarus, for example, a significant part of the populations of spiny reed lives, and the number of large spotted eagles is quite large. In accordance with the Strategy, an inventory of irrigation and drainage systems will be conducted by the Institute of Experimental Botany together with the Forest Institute. It will determine the fate of about 150 thousand ha of drained land. Some of them will re-swamp, and effective reclamation systems stabilize.

Polessky State Radiation Ecological Reserve is the largest (more than 215 thousand ha) in Belarus. The reserve was organized on July 18, 1988 in the Belarusian part of the exclusion zone on the territory of the three most affected areas of the Gomel region—Bragin, Narovlyansky and Khoiniki. On the territory there are 96 abandoned settlements, where before the accident lived more than 22 thousand inhabitants. Belarusian scientists also observe natural phenomena in the exclusion zone on the example of the Polessky State Radiation Ecological Reserve (PSRES), formed around the Belarusian sector of the zone (http://www.zapovednik.by/).

Here there is an increase in the number of animal populations, the appearance of rare species and species that were not previously observed in this area. In turn, the growth of wildlife populations is observed on a pan-European scale, and the increasing anthropogenic impact on the land around the exclusion zone forces animals to move to contaminated areas. This does not negate the fact that in the absence of economic activity of a person, such lands are now an excellent testing ground for the study of wild animals, reproduction of rare species such as bison, lynx, etc. Scientists plan to use the unique conditions of Polessky State Radiation and Ecological Reserve to resume such species lost to Belarus as a European cat.

Legislation on Ecosystem Services and Biodiversity in Belarus

Legislative regulation of environment and ecosystem services is carried out using international agreements, codes of Belarus and government regulations. Legislative acts are grouped in codes: Water, Forest, Air, Code of Subsoil, Land Code. Additionally, legislation adjusts the procedures related to state environmental expertise, strategic environmental assessment and environmental impact assessment (http://www.minpriroda.gov.by/ru/deistv_zakon-ru/).

The ecosystem services accounting in Belarus is distributed among 5 state bodies and is connected with the collection and analysis of statistical data.

1. The Ministry of Natural Resources and Environmental Protection—procurement (harvesting) of wild plants, use of water and natural resources, management of wastes, emissions of pollutants and carbon dioxide.
2. The Ministry of Forestry—harvesting, export of wood and use of forest resources, protection of forests from pests and diseases, hunting activities.
3. The Ministry of Sport and Tourism—touristic activities.
4. The Ministry of Agriculture and Food—fish resources, sowing of agricultural plants by varieties and reproductions, special reports related to elimination of consequences of Chernobyl disaster.
5. The State Inspectorate for the Protection of Fauna and Flora is a specially authorized state body subordinate to the President of the Republic of Belarus that, within its competence, exercises state control over the protection and use of wild animals related to hunting and fishing facilities, tree and shrub vegetation and other wild plants, forest resources.

Special reports related to elimination of consequences of Chernobyl disaster, which are collected by the Ministry of Agriculture and Food from local authorities and companies include information on the contamination of agricultural products with radionuclides of cesium-137 and strontium-90. Upon analysis of collected information it produces an annual report on the implementation of a set of special protective measures on agricultural lands contaminated with radionuclides.

Environmental monitoring in Belarus is carried out within the framework of the National System for Monitoring the Environment in the Republic of Belarus (abbreviated as NSEM, http://www.nsmos.by), established in 1993. This system helps monitor current ecological state and forecast their future status. Annual reports of this system are presented on the site http://www.nsmos.by/content/402.html.

Currently, the NSME includes 11 organizational-independent types of monitoring, the environment, that analyses collected statistical and environmental data:

- Monitoring of land;
- Surface water monitoring;
- Groundwater monitoring;
- Monitoring of atmospheric air;
- Monitoring of the ozone layer;
- Flora monitoring;
- Forest monitoring;
- Monitoring of wildlife;
- Radiation monitoring;
- Geophysical monitoring;
- Local environmental monitoring.

NSMOS is a complex system developing over time and changing conditions. In order to ensure the normative legal basis for the functioning and development of the NSEM for 2011–2015, the President of the Republic of Belarus adopted Decree No. 244 of June 13, 2011 "On the Approval of the State Program for Ensuring the Functioning and Development of the National Environmental Monitoring System in the Republic of Belarus for 2011–2015" (NSMOS 2011).

The legislation of Belarus in the field of ecosystems and biodiversity protection is sufficient to realize the main objectives: protection of species and habitats, maintenance and restoration of ecosystems, achievement of more sustainable agriculture and forestry, to make fishing more sustainable and water resources healthier combating of invasive alien species help stop the loss of global biodiversity. Special measures to collect and analyze data related to Chernobyl disaster are arranged.

In September 2015, the Council of Ministers of the Republic of Belarus approved the National Action Plan for the Conservation and Sustainable Use of Biological Diversity for 2016–2020 and updated the Strategy for the Conservation and Sustainable Use of Biological Diversity (Strategy 2015). The Strategy provides the basis for the formation of a national ecological network, as well as for announcements of biosphere reserves created to ensure sustainable economic development of regions taking into account environmentally oriented use of natural resources and protection of ecosystems. State programs for the development of the system of specially protected natural areas, a scheme for a national ecological network, a scheme for the rational allocation of specially protected natural areas of national importance and regional schemes for the rational allocation of specially protected natural areas of local importance are developed and implemented to conserve biodiversity (http://www.minpriroda.gov.by/ru/deistv_zakon-ru/).

Conclusion

The degradation of ecosystem services could grow significantly worse in the beginning of XXI century and is a barrier to achieving the Sustainable Development Goals 2030. The challenge of reversing the degradation of ecosystems can be partially met under some scenarios, but these involve significant changes in policies, institutions, and practices that are not currently under way. Many options exist to conserve or enhance specific ecosystem services in ways that reduce negative trade-offs or that provide positive synergies with other ecosystem services.

The green economy in the EU focuses on the second-generation environmental problems, which include problems of climate change and biodiversity loss, developing generalized solutions to first-generation environmental problems, which include air, water, soil, considered in the concept of sustainable development.

In 2015 the European Union has funded a project called “Technical Assistance to Support the Development of Green Economy in Belarus”, which also included readiness of national legislation to implementation of ecosystem services (Project 2014). The project suggests to identify the ecosystem service in national legal instruments, choose the scenario: which ecosystem services using market instruments will be presented in the short and long term.

National Report (2015) “On Human Development in the Republic of Belarus—-Competitive advantages of the regions of Belarus” includes the strategy of ecosystem services development, introduced by the Ministry of Economy of Belarus. The strategy includes main ecosystem services being developed in Belarus: provision of fresh water of normative quality, carbon uptake, preservation of biodiversity and aesthetic properties of landscapes. The formation of the sector of ecosystem services can be considered as part of the national economy and the economy of regions integrated into international relations. In the domestic market, the ecosystem services sector includes the following subsectors: trading in greenhouse gas emission quotas; Cultural ecosystem services; Wastewater treatment. However, it is stated that the development of a legislative base in the Republic of Belarus is necessary to create the subsector “Trade in quotas for greenhouse gas emissions”.

Belarus has also some unique practices in the field of ecosystem services management, which also may be analyzed and disseminated as best practices of ecosystem accounting and management:

– Forest resources management related to wild medicinal plants, berries and mushrooms. This procedure adjusts with the Resolution (2016) “On the establishment of the tax value for spurious forest management and harvesting of secondary forest resources”, which introduces a tax on the collection of mushrooms, berries, herbs and so on.
– Cultivation of lands contaminated with radionuclides after Chernobyl disaster and monitoring of radioactive contamination, especially related to transponder contamination between Belarus, Russia and Ukraine.

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Zenchanka Siarhei is a professor of the chair of Management, Accounting and Finance of the Minsk Branch of the Plekhanov Russian University of Economics. He has a Ph.D. in Applied Science. His research focus is in the areas of the sustainable development and education for sustainable development.

Gorbatchev Nikolai is Deputy Director for Research and Information Technologies of the Minsk branch of the Plekhanov Russian University of Economics. He is associate professor of the Department of Economics. He has a Ph.D. in Economics ("Mathematical and Instrumental Methods of Economics"). He is the author of more than 50 scientific works on modeling of information systems, sustainable development, e-learning technologies.

Community Action for Biodiversity and Forest Conservation and Adaptation to Climate Change in the Wild Coffee Forests (CAFA)

Svane Bender and Mesfin Tekle

Abstract The Afromontane cloud forests of the Kafa Biosphere Reserve in south-west Ethiopia are considered to be the origin and centre of *Coffea arabica*'s genetic diversity and home to many rare species. Together with the area's numerous wetlands, they form a carbon sink of superregional importance. However, studies have shown that the habitats are threatened by overexploitation and climate change. In addition, the natural connectivity of the local population, in particular of young people to their natural environment and the loss of knowledge on traditional use and cultivation systems is notable. NABU, a German NGO, therefore started working towards climate and biodiversity conservation and supports the local population to independently ensure the long-term conservation of key ecosystems and their services for livelihoods. This paper gives an insight into Participatory Forest Management at the wild coffee forests at Kafa Biosphere Reserve. The authors outline the proactive planning process, constraints and limitations for management as well as lessons learned from practical implementation of the concept. The results may be used by practitioners such as representatives from NGOs, administrations of protected areas and communities.

Introduction

Ethiopia is a world gene centre of origin (McKee 2007) and is considered to be one of world's most biodiverse countries (BIDNTF 2010). The remnant highland forests, although declining, harbour invaluable key ecosystems. The current 3% forest cover descended from a 40% forest cover since the 1970s and still continues to

S. Bender (✉)
The Nature and Biodiversity Conservation Union (NABU), Charitéstr, 3,
10117 Berlin, Germany
e-mail: Svane.Bender@NABU.de

M. Tekle
The Nature and Biodiversity Conservation Union (NABU),
NABU Project Office, Bonga, Ethiopia
e-mail: Mesfin.Tekle.NABU@gmail.com

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decrease at an annual rate of between 80,000 and 200,000 ha. If this trend continues, it can be assumed that the marvellous forests will have disappeared in 2020 (EFAP 1994). Deforestation and degradation are key drivers attributed to population growth, firewood extraction, agricultural encroachment, illegal settlement and expansion of infrastructure and commercial farming.

Participatory Forest Management (PFM) in Ethiopia

FAO (2016) defines participatory forestry as "processes and mechanisms which enable people with a direct stake in forest resources to be part of decision-making in all aspects of forest management, including policy formulation processes". In Ethiopia, Participatory Forest Management (PFM) has been in practice since the mid 1990s. The term PFM is used to describe forest management systems in which communities (forest users and managers) and government services (forest department) work together to define rights of forest resource use, identify and develop forest management responsibilities, and agree on how forest benefits will be shared (FARM-Africa and SOS Sahel Ethiopia 2007). According to MoA, the Ethiopian Ministry of Agriculture (2012), practical experiences and lessons have proven that the communities in and around forested areas can be part of the solution for reducing deforestation and regeneration of forest resources. These practical experiences gained within Ethiopia, have repeatedly shown that the participation of the communities in the negotiation and drafting of the forest management, conservation and use plans strongly contributes to create community ownership and ensures community involvement at all stages of forest resource management (Befikadu and Luwiza 2014). Participation is believed to be the crucial element for sustainable forest management.

Essentially, the PFM process leads to the establishment of a forest user group (FUG), which enters into a PFM agreement with the district's Woreda Office of Agriculture. The agreement as well as a forest management plan set down the rights and responsibilities of the forest user group and the Woreda Office of Agriculture. The management plan lays out the protection, utilization and development of the PFM area. Use rights usually involve the harvesting of Non-Timber Forest Products (NTFP) and limited amounts of firewood and construction wood. In return, the forest user group commits to protecting and sustainably using the PFM area with the support from the district and communal administration. This should lead to a reduction of illegal activities such as clearing for agricultural land, free livestock grazing, logging, firewood collection and charcoal production. PFM agreements may also involve the rehabilitation of previously deforested or degraded land planting native tree species.

NABU's Work in Ethiopia

Since 2006 NABU has been supporting people and nature in Ethiopia. NABU is a registered international NGO and operates currently two offices in the capital Addis Ababa and four project offices in different part of the country, partly together with partners. Starting with the establishment of Kafa Biosphere Reserve, NABU pursued implementing large scale conservation projects in the area, funded by the German government. NABU's current project comprises the following components: (i) adaptation of agriculture to climate change for soil protection and food security, (ii) improvement and fostering of Participatory Forest Management, (iii) introduction of community-based wetland protection, (iv) local anchoring of community-based monitoring with nature rangers, (v) expansion and marketing of regional products, (vi) Fostering capacity building and education and (vii) project-accompanying information campaign. Upon the establishment of Kafa Biosphere Reserve, NABU, UNESCO and the Ministry of Science and Technology of the Federal Democratic Republic of Ethiopia signed a Memorandum of Understanding to establish a network of biosphere reserves in Ethiopia. Since then NABU became one of the main stakeholders supporting UNESCO biosphere reserves in the country. NABU implements projects on biosphere reserve management, sustainable development and income generation conservation, rehabilitation and adaptation to climate change. In particular, NABU promotes community-based resource management systems as an effective tool against habitat fragmentation and degradation.

Implementation Practice of PFM in Kafa Biosphere Reserve

Forest fragmentation is a major cause of forest loss in Kafa Biosphere Reserve (Dresen 2011). Even at a low deforestation rate, fragmentation can lead to a reduction or even a complete loss of contiguous forest and create forest islands with serious consequences on biodiversity and ecosystem functions, thereby increasing people's vulnerability to climate change (Dresen 2011; De Vries and Herold 2014). A review on PFM effectiveness in Kafa Zone concluded that PFM has shown positive impacts both on the state of the forest and living condition of participant households at least within the project life time (Gobeze et al. 2009). PFM also (i) promotes awareness on forests, (ii) facilitates institutionalization of increased community participation in forest management and regulates open access and (iii) contributes towards social equity in terms of gender and ethnic minority groups.

Between December 2009 and February 2013, NABU supported the establishment of 16 PFM sites covering more than 11,000 ha at the Kafa Biosphere Reserve. The PFM sites are located in five of the ten Woredas (districts) of the reserve and were selected according to criteria such as high pressure on the forest as well as recommendation from the local government and urgent demand from local community in the face of losing the forest to agro-investments. The following methodology was applied by NABU in line with current practice (e.g. FARM-Africa and SOS Sahel Ethiopia 2007) for the establishment of the PFM sites:

i. Identification of potential PFM areas;
ii. Consultation, awareness creation and data collection involving all forest users;

iii. Nomination of planning committees with 112 members, training of members, implementation of Rapid Forest Assessments;
iv. Participatory forest boundary demarcation including identification of core areas;
v. Mapping and map creation (QGIS);
vi. Participatory forest resource assessment with communities and government representatives;
vii. Participatory development of management plans and contractual agreements for each PFM site;
viii. Signing of agreements and official handing over by government.

In the following, the process is being described in detail. In the course of the establishment of PFM groups, NABU conducted intensive information and awareness creation sessions inviting all 7,778 forest users, grouped according to their forms of use for instance forest users for honey production or collection of wild coffee. After clarification of user rights, requirements and management, the communities were encouraged to nominate a “Plan-Preparatory Committee” (PPC) which comprised representatives from the respective forest patches and sub-villages and included women as well as youth and minority group members. The number of PPC members ranged between 12 and 20 people depending on the size of the forest and the village. NABU provided various forms of trainings and capacity building to the PPC nominees such as Participatory Resource Appraisal tools (PRA) including resource mapping (see Fig. 1), social mapping, transect walks, participants observation, rankings (preference/pair-wise/matrix), problem analysis, identification of the forest resources and associated traditional users. Following this, the status of the forest, the course of the forest patch’s boundaries and existing border conflicts, the types of use (timber/NTFP) and users as well as the forms of existing user arrangements are being assessed by the committee supported by NABU.

In addition, the users’ social and cultural habits and traditions are being investigated as well as the livelihood status and dependence using participatory methods. This entire process helps to build up knowledge and understanding at stakeholders’ level for the value of the forest, livelihood dependencies, roles and responsibilities and societal dynamics. The FUGs were encouraged to comment and endorse the findings which were reflected under guidance of NABU and to plan next actions. Hereupon, NABU supported the PPC to conduct participatory forest resource assessments (PFRA). At the same time GPS data were collected in the field and PFM site maps created (see example PFM map in Fig. 2) and finally the boundaries were demarcated in the field by painting trees.

The habitual use forms, usufruct arrangements, traditional user rights and territories were being assessed and data such as area calculation, forest condition estimations (i.e. basal area, canopy cover, degradation rate estimation and tree species composition calculation) collected. NABU facilitated the determination of forest resource use trends (improving/stable/reducing), key potentials, main problems, drivers and available opportunities at forest patch level. Based on the findings, NABU supported the PPC to reflect and generate proposals for management for conservation, develop-

Fig. 1 Participatory forest resource assessment with communities. *Picture credit* Angelika Berndt

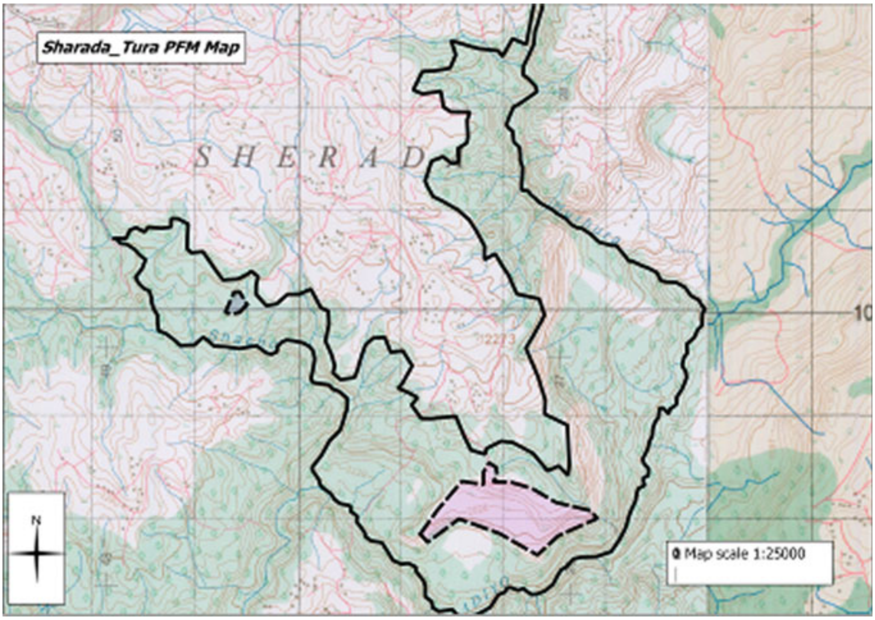

Fig. 2 Example of PFM site boundaries in Kafa Biosphere Reserve (Sharada PFM). *Source* NABU

ment or enhancement and utilization. Alternative livelihood improvement activities were also being discussed. Finally, NABU closely supported the drafting of the forest management plan focusing on three main activities and two cross-cutting tasks: forest conservation, forest development and/or enhancement and forest utilization as main activities and forest monitoring and livelihood improvement activities as cross-cutting tasks. The draft plan was then presented to FUGs for discussion and approval. Once endorsed by the community, the plan was submitted to the relevant offices (agriculture or forest section) for assessment and approval. Meanwhile, the PPC also developed byelaws and agreement documents that were simultaneously submitted to the offices. Finally, an agreement between the relevant government officials and representatives of the FUGs was signed.

In general, the establishment process contributes to the following key aspects: (1) Understanding and knowledge building, (2) definition of territory and habitual resource use, (3) formalization of the rights of traditional users while compromising the emerging needs and shortage or dwindling of forest products through negotiating and compromising, (4) determining forest management objectives for optimum utilization, protection and regeneration and forest/product enhancement.

This paper summarises methods, practical implementation and findings of a case study implementing Participatory Forest Management in Ethiopia. The authors draw lessons learned to be used by practitioners such as NGO representatives, administration of protected areas and communities.

Methods

Study Site: The Kafa Biosphere Reserve

The Kafa Biosphere Reserve is situated in Southwest Ethiopia (latitude: 35°29′50.55″ to 36°47′33.78″ North/longitude: 35°48′50.57″ to 35°44′34.30″ East, see Fig. 3). It was designated as UNESCO biosphere reserve in 2010. Its planning and establishment as one of the first biosphere reserves of Ethiopia, was a widely appreciated success under the technical guidance of NABU and within the framework of a German Public-Private-Partnership project. It has a forest cover of 47% with 4% (28,172 ha) being core zone serving as a refuge for endemic or endangered species (Dresen 2011). Administratively, the reserve comprises ten Woredas (districts), 250 rural Kebeles (lowest administrative unit) and 25 towns.

With a size of 760,000 ha, the reserve covers also three Regional Priority Forest Areas (compare Fig. 4) designated for national protection. It harbours 45,000 ha of extensive wetlands and floodplains as well as the Omo-Gibe and Baro-Akob basins and has been recognised for its remarkable species endemism (NABU 2017). The area is particularly noteworthy as global in situ gene bank being the origin and centre of *Coffea arabica*'s genetic diversity. Due to this fact, the area has been rated at a value of $1.5 billion (Hein and Gatzweiler 2006). Along with the forests, the

Fig. 3 Location of the Kafa Biosphere Reserve at national and regional scale (NABU 2017)

aquatic habitats are the main suppliers of ecosystem services to local communities and provide animal fodder, building materials, medicinal plants etc.

650,000 people live in the premises of Kafa Biosphere Reserve. With an average of 98% inhabitation per km^2, the range extends from 52 to 210 inhabitants per km^2 (SNNPR 2013). According to Chernet (2008) the population consists ethnically of 81% Kaffichos, 6% Bench, 6% Amhara, 2% Oromo and 5% minorities (Manjas). More than 90% of the inhabitants' livelihoods depend on subsistence farming, the sale of coffee (10% forest coffee/65% garden coffee), forest honey and the use of natural resources e.g. for food, fuel, building material and medicinal plants or spices (SNNPR 2013). Mainly grain is being cultivated, including the local Ethiopian grain species teff (*Eragrostis teff*), legumes and the locally important Abyssinian banana (*Ensete ventricosum*), whose starch-rich stem is fermented for bread. The most common livestock is cattle (7.5 per household, 2011/2012, local government), followed by poultry, sheep and goats. Wild coffee harvesting has been practised over centuries; complex tenure arrangements and traditions and rites have been developed.

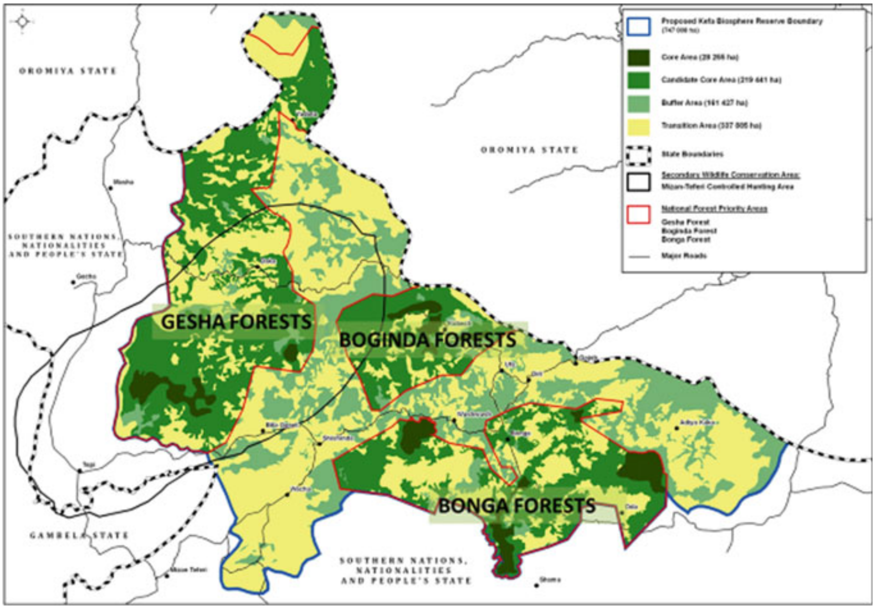

Fig. 4 Kafa Biosphere Reserve, its protection zones (core/buffer/transition) and Forest Priority Areas. *Source* Dennis Moss Partnership (2009)

Impacts of Climate Change and Threats to Biodiversity

Increasingly, the natural ecosystems of Kafa Biosphere Reserve are being degraded. The degradation also endangers important ecosystem functions and subsequently increases the human vulnerability to climate change. Due to climate change, there is a rise in temperatures, changed precipitation patterns, more frequent droughts and a threat of the long-term water supply. At the same time, the degradation enforces surface run-off and fosters soil erosion, with negative consequences for soil fertility and water quality through sedimentation and reduced ground-water formation. Besides severe impacts on biodiversity, the loss of forests has also led to freeing a considerable amount of CO_2 and impair the forest's function as a carbon sink. Climate change impacts like irregular and heavy rain falls, extreme droughts and heavy frosts as well as proliferation of pests are challenging farmers and ecosystems. In particular the wild Arabica coffee is at risk (Davis et al. 2012). Though laws and regulations for the protection and utilisation of forests and biodiversity exist in Ethiopia, insufficient capacities of the responsible institutions prevent an effective implementation.

Data Collection

In 2014, NABU decided for an evaluation of the 16 PFM sites by external experts in order to (i) assess existing conditions of forest management; (ii) identify the effectiveness of the established PFM sites; (iii) see constraints, challenges and underlying causes for failures based on the forest management plan in each PFM sites; (iv) identify measures for improved PFM implementation, management and awareness creation. The evaluators used both primary data and secondary data collection: Guided interviews with 146 PFM committee members and reflection workshops with 350 user community representatives in five Woredas served for data verification.

The authors are aware that the presented data is specific to the case of Kafa Biosphere Reserve and may therefore have limitations. Nevertheless, the authors' intention is to support other areas in Ethiopia or beyond on their way to establish PFM and share lessons learned for practitioners.

Results and Discussion

For better understanding, the evaluated 16 PFM sites' basic data are compiled in Table 1 (see underneath) showing the size of each PFM size and number of members of each group. All of the 16 PFM sites were linked to coffee and honey cooperative unions based in the Zonal capital Bonga in order to create income from forest honey and coffee being harvested in a sustainable manner. For forest development and improvement, the PFM sites were provided with 5.2 kg of tree seeds (e.g. *Prunus africana, Cordia africana, Hagenia abyssinica, Millettia ferruginea, Juniperus Procera*). In addition, the PFM communities collected locally available tree seeds and cultivated those. As a result, more than 100,000 native trees were planted by the members following the forest development and conservation goals in the management plan (Fig. 5).

All PFM sites obtained support for a smooth working environment like nursery tools, office buildings, stationeries, office furniture and vouchers. For enhancing capacities, the PFM committee members received regular trainings. All PFM groups also received livelihood related support: 114 modern beehives, restocking of beehives with bees and other related equipment. To improve the honey production and thus the communities' income, technical support and upgrading to a cooperative level was provided. The transformation of four PFM groups into cooperatives enabled them to professionalize the marketing of honey and wax through the honey head union. Two PFM sites were afterwards able to sell 10.2 t of honey and 121 kg of bees wax through the union and earned more than 750,000 Ethiopian Birr (~24.200 Euro).

The results of the assessment proved high involvement and participation of all relevant actors for instance in the preparation of each management plan, border negotiation and setting of rights and responsibilities. All PFM members formally acquired legal use rights recognition on the identified natural forests by the govern-

Table 1 Basic data on the established PFM sites

PFM site	Woreda	Forest area (ha)	Date of handing over of PFM site	PFM members		
				Male	Female	Total
Kumiti	Gimbo	386.42	11/2011	126	6	132
Wohabina Gori	Gimbo	693.26	02/2013	314	313	627
Gacemo	Gimbo	368.84	12/2012	260	256	516
Wodito	Gimbo	1235.23	12/2012	384	316	700
Buna Shuniyo	Decha	831.75	11/2011	174	10	184
Gora	Decha	400.40	04/2012	133	26	159
Boba Meliyo	Decha	742.52	01/2012	306	79	385
Eta Hachecha	Decha	837.75	05/2012	138	111	249
Shuno Yerina	Gesha	448.90	11/2011	166	3	169
Dadati	Gesha	247.00	11/2011	129	17	146
Hawurina Kukir	Saylem	450.80	07/2012	156	171	327
Halo Ganity	Saylem	1259.70	12/2012	113	129	242
Eno	Adiyo	1138.90	06/2013	544	512	1056
Yecha	Adiyo	919.00	06/2013	214	235	449
Mediwuta	Adiyo	827.25	12/2013	420	437	857
Sharada	Adiyo	934.00	12/2013	475	520	995
Total		11,721.72	11/2011	4,052	3,141	7193

Source Befikadu and Luwiza (2014)

ment. Nevertheless, the activity performance for instance on forest protection and development for instance replanting differed between the PFM sites. When it comes to economic benefits for the community members, the assessment revealed significant amounts of cash of 1,100,000 Ethiopian Birr (~35,500 Euro) from the sale of NTFPs, penalties and compensation fees.

Conclusions and Recommendations for Practitioners

PFM is a forest management system that showed to be a complementary mechanism for safeguarding forests and biodiversity, while respecting traditional users. The value adding to the forest as well as the involvement and handing over of man-

Fig. 5 Forest group members assessing the status of seedlings. *Picture credit* NABU/Abdurazak Sahile

agement responsibilities create ownership and awareness at community level. Thus, forests at Kafa Biosphere Reserve which were suffering from open access before, are being guarded, protected and developed by the community. Moreover, the FUGs started to earn significant amounts of cash from the sale of NTFPs, penalties and compensation fees. Nevertheless, it requires constant follow-up and technical support by the local government or by NGOs in order to ensure PFM is run effectively. Most PFM groups were performing fine when it comes to implementing the utilization plan, while forest development and forest protection activities were not being equally. The authors suggest to include PFM into the zoning and daily support scheme of an already existing protected area like a biosphere reserve for constant support, guidance and monitoring. Therefore, a zoning element could be added to the other zones of the protected area for instance "community-based PFM site". In general, PFM is considered as a valuable tool for forest and subsequently biodiversity conservation even though it requires constant input—it can be assumed that some forest sites would be very degraded or even eliminated by now if PFM would not have been established, halting open access or investment projects.

The following was found to be of high importance for successful PFM establishment in Kafa Biosphere Reserve:

- **Secure legal recognition and accountability**: User rights must be vested for instance by bylaws and agreement documents. This will enable the PFM site members to take legal actions, e.g. penalty fees against trespassers and illegal use of their resources.

- **Create a strong link and cooperation with local government institutions**: A lack of support from governmental offices has been proven to be a hampering factor for an effectively working PFM group.
- **Respect gender and social aspects**: In the course of the PFM scheme both the Manja minority and women were recognized equally with no restrictions, leading to a better positioning at and integration into society.
- **Assure traditional user rights**: With the act of formally recognizing the traditional use rights of forest user groups, a sense of ownership developed in the communities for protection and sustainable use of their forest resources.
- **Increase the value of the forest for communities**: By replanting and tending seedlings in the forest, the communities were able to increase the forest cover and with it the value of the forest. This may result in higher appreciation and awareness of the value of natural ecosystems and their services.
- **Introduce NTFP for alternative income generation**: By offering the communities NTFP like spices, coffee or traditional beekeeping systems, the forest user groups show more commitment for conserving the forest while getting a higher income.
- **Create awareness with members and adjacent communities**: In order to reach a strong sense of ownership and affiliation amongst the members, a constant awareness creation is needed. The contents of byelaws and management plans should be accessible and transparent.
- **Support a smooth working environment**: In order to ensure a proper documentation and financial management, as well as the opportunity to hold meetings and be visible in the community, it is recommended to establish basic offices for each PFM group. Committee members should be regularly trained, but also evaluated and, if needed, replaced.
- **Ensure regular monitoring, documentation and reporting**: The agreed management plan and byelaws have to be monitored properly and transparently and activities have to be documented. In addition, patrolling is easier to organize when time schedules are being set and agreed and reporting and evaluation formats are being provided.
- **Provide livelihood support**: Accompanying the forest development, it proved advisable to support the forest users with livelihood support like beekeeping, spice production and other NTFP.
- **Demarcate PFM boundaries**: For visibility, understanding and ownership it proved valuable to clearly demarcate PFM zones in the field (e.g. paint marks on trees, planting of border lines with non-native tree species).

NABU continued its work on PFM in the Kafa Biosphere Reserve after the described first implementation phase and will continue doing so until 2019. It is planned to further strengthen the almost 30 PFM sites established by NABU through regular training, livelihood support and the development and legalisation of common standards for PFM sites. The latter will also help to easier measure the effectiveness of PFM groups in future (See Fig. 6).

Fig. 6 Content FUG at Kafa Biosphere Reserve. *Picture credit* NABU/Svane Bender-Kaphengst

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Impact of Climate Change on Sawfly (Suborder: Symphyta) Polinators in Andalusia Region, Spain

Jelena Barbir, Luis Oscar Aguado Martín and Xavier Rodriguez Lloveras

Abstract Sawflies (Symphyta) are insects widely distributed throughout the world, but mostly abundant and diverse in the temperate regions of the Northern hemisphere. In Spain, they are linked to vegetation typical for aquatic environments (e.g. ponds and streams). While many sawfly species are serious pests of horticulture and forestry, all sawflies found in the Andalusia Region are important pollinators. In order to evaluate if climate change affects sawflies in Spain, their present appearance and distribution sampled form 2013 to 2016 was compared with the data collected from 1920s to 1971. The results showed that biological cycle of some Symphyta species was advanced 20–30 days when compared with the dates of their usual presence in 1950–70s. While some species have been frequently found in the same areas as 50 years ago, changes in climate affected vertical displacements to higher altitudes of other studied sawfly species. The most important findings of this study showed that in the 21st century four species (*Megalodontes bucephalus, Macrophya militaris, Strongylogaster multifasciata, Dolerus* (*Poodolerus*) *puncticollis*) were not observed in any location nor sampling area, meaning that these species (important specialized pollinators) disappeared from the Andalusia region.

J. Barbir (✉)
International Climate Change Information Programme (ICCIP), Research and Transfer Centre, "Sustainability and Climate Change Management" (FTZ-NK), Ulmenliet 20, 21033 Hamburg, Germany
e-mail: jelena@barbir.com.es

L. O. Aguado Martín
Freelance Entomologist—Andrena Iniciativas y Estudios medioambientales S. L., Valladolid, Spain
e-mail: oscaraguado@lepidopteros.com

X. Rodriguez Lloveras
Geological Hazards Prevention Unit, Institut Cartogràfic i Geològic de Catalunya, Parc de Montjuïc, 08038 Barcelona, Spain
e-mail: xavier.rodriguez@icgc.cat

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Introduction

Sawflies (Symphyta) are insects widely distributed throughout the world, but mostly abundant and diverse in the temperate regions of the Northern hemisphere where some species are characterized as important pests [e.g. *Neodiprion sertifer* (Geoffroy 1975) known as the European pine sawfly]. In Spain, sawflies are linked to vegetation typical for aquatic environments (e.g. ponds and streams) and many species are also serious pests of horticulture and forestry where each species of sawfly feeds on a specific host. On the other hand, many sawfly species are important pollinators of wild flowers in Southern Spain.

Sawflies (Symphyta) are wasps with a series of very primitive characteristics. They have not developed the agile articulation of the abdomen that characterizes the majority of Hymenoptera, nor are they specialized, such as the Apocrita (the rest of the bees and wasps), which have a drill or a stinger obtained throughout the evolution of the group. In addition they are not organized socially either, and their larvae conserve in their majority the phytophagous alimentary habits that are considered characteristic of the first members of the Hymenoptera order. The first Symphyta date from the Triassic, about 220 million years ago. The superfamily of the Tenthredinoidea, it seems that it had its origin later, in the Jurassic period of the Secondary Era, something more than 120 million years ago. This data indicates that they are still about 10 million years older than the butterflies (Viitasaari 2002).

In many sawfly species, virgin females produce sex pheromones to attract males. In these cases the copulation between the two sexes takes place. However, there are many species in which males are very rare such as *Tenthredo* (*Cephaledo*) *Meridiana* (Serville 1823), *Macrophya* (*Macrophya*) *militaris* (Klug 1817) and others, and even in some species the male is unknown. In these species the females are parthenogenetic and the eggs are fertile without having previously copulated. Virtually all generations are parthenogenetic, and usually only females emerge. However, occasionally a functional male may appear, possibly as an adaptive response to environmental changes (Burke 1962), given that sexual reproduction ensures a greater genetic variety, favouring the appearance of individuals that adapt to the new conditions. Parthenogenesis can be adequate when a species is perfectly adapted in an immutable biotope. Considering this primitive biology of sawflies, they can be easily affected with climate change or other changes in environmental conditions (Aguado Martin 2007).

Climate change affects biological cycles, habitats and migrations of many different species (Hegland et al. 2009; Scaven and Rafferty 2013). Species may face extinction if habitat sizes shrink (for example, at the pole or at mountain points), or if immigration barriers or limited dispersal ability prevent them from reaching newly suitable habitat (Lambers 2015). Since in Spain sawflies are linked mainly to vegetation typical for aquatic environments, they are vulnerable to changes in climate (especially humidity).

Unfortunately, research trends are mainly related to the species that directly affect agricultural production or other economic interests, while species that do not directly treat or benefit humans are slightly disregarded. For example, direct effects of climate change on the most important crop pollinators have received much attention lately, due to their crucial function in crop production (Scaven and Rafferty 2013; Barbir et al. 2014). Regarding sawflies, mainly important pests were studied in depth e.g. wheat stem sawfly (Perez-Mendoza and Weaver 2006), apple sawfly (Graf et al. 2001), pine sawfly (Sholes 2011), etc. In all these studies, changes in temperatures affected biological cycle of sawflies, forcing them to vertically migrate, adapt to present conditions or in worst cases to face extinction. In this study, all sawfly species present in the study area were monitored and field data was compared with climatic data. The main objective of the study is to evaluate if changes in climate affect distribution and presence of sawflies in Andalusia region.

Methodology

Identification of Sawfly Species in the Andalusia Region

The study presents some interesting findings collected in the 20th century and compares it with recent data collected in the same locations. The research started with the compilation of data series regarding the presence of different sawflies in Andalusia region collected by the Institute of Acclimatization of Almeria in the period from 1920s to 1980s (20th century). Subsequently, in the period between 2011 and 2015 (21st century) several samples were taken in the same locations and periods as in 20th century. This data was collected in order to compare present distribution of the sawfly species with their distribution detected in the 20th century.

In each of the sampling locations regular transects were carried out, during the different seasons, sweeping with the entomological sleeve different types of vegetation and substrates present in each of the previously selected habitats.

All material captured in the field was labelled including relevant information: date, location, UTM, altitude, type of vegetation, temperature, humidity and observations. Subsequently, captured sawflies were identified in the laboratory. In the specific case of some species, larvae and their captive breeding were captured until adults emerge, in order to be able to obtain more details about their biological cycle.

Study Area

Andalusia sits at latitude between 36° and 38° 44′ N, in the warm-temperate region. In general, it experiences a hot-summer Mediterranean climate, with dry summers. Study was conducted in 13 locations distributed along the Southern and Eastern part of the Andalusia region (Table 1). Three locations were located in Almeria province, four in Malaga province and six in Granada province. The locations were chosen in the first period when samplings were conducted (in 20th century) where the main criteria for choosing specific location was presence or absence of sawflies in that area.

As shown in the table above (Table 1), the sampling sites were located in different attitudes (from 524 to 2500 m) what provided the necessary insight in two most important climatic parameters—temperature and humidity. In order to better visualize locations of sampling spots, locations where grouped in three areas: Malaga (1), Sierra Nevada (2) and Alto Guadiana (3) (Fig. 1). Each area is characterized by different microclimate due to differences in altitude, temperature and humidity (Figs. 1, 2, 3, 4 and 5).

Table 1 Sampling locations

Locations	Municipality	Province	Altitud (m)
Albergue Universitario, Sierra Nevada	Pradollano	Granada	2500
Veleta, Río Dilar, Sierra Nevada	Pradollano	Granada	2500
Horcajo Trevelez - Sierra Nevada	Trévelez	Granada	2176
Puerto de la Ragua Sierra Nevada	Bayárcal	Almería	2041
Refugio Postero Alto, Barranco de Alhorí	Jeréz del Marquesado	Granada	1900
Barranco de Molina, Sierra María	María	Almería	1649
La Sagra, Fuente Tornajo	Huéscar	Granada	1558
Sierra Alcojona	Ronda	Málaga	1498
Puerto del Lobo, Sierra Nevada	Víznar	Granada	1386
Alpujarras	Juviles	Granada	1255
Puerto del Saucillo, Sierra de las Nieves	Yunquera	Málaga	1200
Alpujarras	Laujar de Andarax	Almería	804
Nacimiento de Moyano, Sierra de Ronda	Gaucín	Málaga	612
Benaoján-Montejaque, Grazalema	Benaoján	Málaga	524

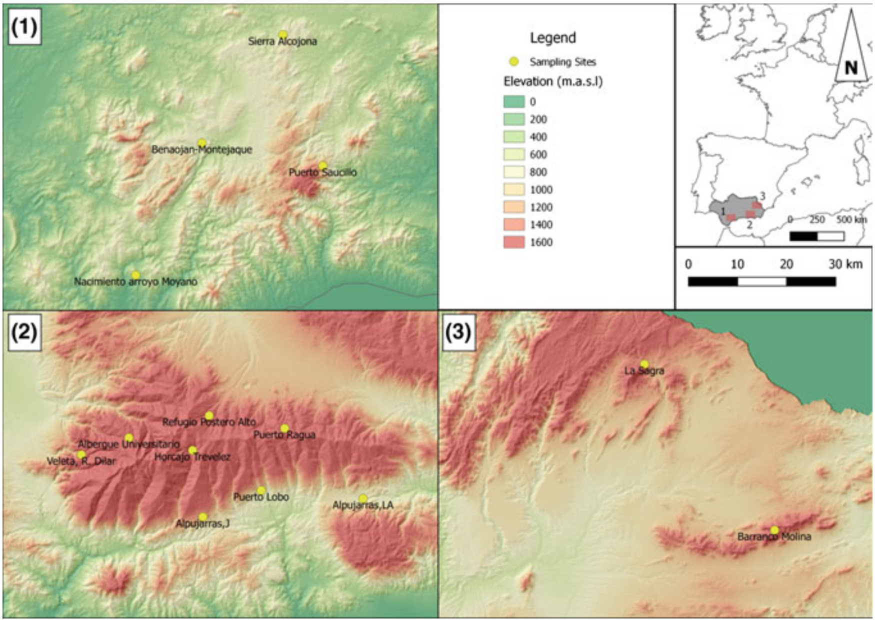

Fig. 1 Locations and altitudes of sampling sites: (1) Malaga; (2) Sierra Nevada; (3) Alto Guadiana

In Malaga (Fig. 1—1) the lowest altitude is 524 m.a.s.l., located at Benaoján-Montejaque, Grazalema. The highest altitude in Malaga (Fig. 1—1) is 1200 m.a.s.l. at Puerto del Saucillo, Sierra de las Nieves. In accordance with the land cover data from CORINE (Bossard et al. 2000), the vegetation on the lower altitude area is dense scrubland with oak trees. In high areas vegetation is dense coniferous forest and scrubland. In addition, there are many streams in this area (Zarzalones, Quejigales, and Moyano) along with the River Verde, which allows the existence of pastures with different plant species (fam. Ranunculáceae, Pinsapo masses, junipers, oaks, melojos, cork oaks, hawthorns, gorse, rosemary, lavender and rockrose).

In Sierra Nevada (Fig. 1—2) the lowest altitude is at Juviles, Alpujarras, with 1255 m.a.s.l.. The highest altitude is at Albergue Universitario and Veleta, Río Dilar, in Sierra Nevada, with 2500 m.a.s.l. In accordance with the CORINE Land Cover data, the vegetation on the lower altitude area is scrubland with patches of coniferous forest. In high areas vegetation is scarce, mainly pasture and scrubland.

In Alto Guadiana (Fig. 1—3), only two sampling sites are present at similar altitudes (1498 and 1558 m.a.s.l.). CORINE Land Cover data indicates scrubland and coniferous forest and dry-land crops.

Data Collection and Analysis

Locations where sampled in the 20th century (from year 1926 to 1983) and again in the 21st century (from year 2011 to 2015). Scientific approach was based on the data available from the Acclimatization Institute of Almeria, collected in the 20th century. These data have been compared with the data collected in the 21st century, defining a set of general displacement trends between the two intervals. In each location where the species suffered changes the trends have been identified.

The altitude has been considered as a classification factor, since it is closely related with important changes in humidity and temperature even under small spatial distances. These changes in climatic variables can provoke migration of the species to different areas. For this reason, the altitudinal analysis has been complemented with the climatic data of the Andalusia region obtained from the Environmental Information Network of Andalusia (REDIAM 2017). The data used is: (a) Annual average temperature during the most recent reference period considered by the IPCC, 1971–2000 (Hoerling et al. 2011; Kirtman et al. 2013), and the last five years of available information (2010–2015); and (b) Annual average of Humidity Index (HI) calculated as precipitation (P) divided by the potential evapo-transpiration (ETP), during the intervals 1971–2000 and 2010–2015.

The comparison between these two factors and the sampling sites allows discussing the migration trends of each species at local and regional scales.

Results

Sawfly Species Identified in the Study Area

Field samplings in the Andalusia Region were preformed between 1926 and 1983 and allowed identification of 22 species of sawflies (Table 2). The most abundant family is Tenthredinidae with 17 different species, while two species from Argidae and Cimbicidae families were detected, and one species *Megalodontes bucephalus* (Klug 1824) from Megalodontesidae family was located in the study area (Table 2).

The most abundant species in the study area were polyphagous sawflies from Superfamily Tenthredinoidea (both adults and their larvae). Even within the Superfamily Tenthredinoidea some specialized species in the sub-family Selandriinae were found. This is one of the most primitive sub-families, composed of numerous species belonging mainly to the genus *Dolerus*. These primitive sawflies species are always linked to only one genus of primitive plants (genus *Carex*, *Equisetáceas* (genus *Equisetum*) and *Juncaceas* (*Juncus*)). These plants normally grow in meadows, peat bogs and swampy environments and for that reason the sawflies feeding and pollinating them occupied the same habitat.

In 21st century, each location was studied again and the same species as in 20th century were searched, as well as connection between distribution of sawflies

Table 2 Species identified in the study area

Order	Family	Sub-family	Genus	Specie	Author	Sub-specie
Hymenoptera	Argidae	Arginae	*Arge*	*melanochroa*	Gmelin (1790)	
Hymenoptera	Argidae	Arginae	*Arge*	*ochropus*	Gmelin (1790)	
Hymenoptera	Cimbicidae	Abiinae	*Abia*	*sericea*	Linnaeus (1767)	
Hymenoptera	Cimbicidae	Coryninae	*Corynis*	*dusmeti*	Konow (1905)	
Hymenoptera	Megalodontesidae	Megalodonteninae	*Megalodontes*	*bucephalus*	Klug (1824)	
Hymenoptera	Tenthredinidae	Selandriinae	*Dolerus (Achaetoprion)*	*uliginosus*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Selandriinae	*Dolerus (Dolerus)*	*germanicus*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Selandriinae	*Dolerus (Cyperolerus)*	*anticus*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Selandriinae	*Dolerus (Poodolerus)*	*puncticollis*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Selandriinae	*Strongylogaster (Strongylogaster)*	*multifasciata*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Macrophya (Macrophya)*	*annulata*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Macrophya (Macrophya)*	*militaris*	(Lacourt, 1999)	

(continued)

Table 2 (continued)

Order	Family	Sub-family	Genus	Specie	Author	Sub-specie
Hymenoptera	Tenthredinidae	Tenthredininae	*Macrophya (Macrophya)*	*montana*	(Lacourt, 1999)	*montana*
Hymenoptera	Tenthredinidae	Tenthredininae	*Rhogogaster (Cytisogaster)*	*picta*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Rhogogaster (Rhogogaster)*	*chlorosoma*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Tenthredo (Cephaledo)*	*meridiana*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Tenthredo (Elinora)*	*baetica*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Tenthredo (Eurogaster)*	*mesomelas*	(Linnaeus, 1758)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Tenthredo (Eurogaster)*	*mioceras*	(Lacourt, 1999)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Tenthredo (Tenthredo)*	*violettae*	(Lacourt, 1973)	
Hymenoptera	Tenthredinidae	Tenthredininae	*Tenthredo (Tenthredopsis)*	*scutellaris*	(Fabricius, 1804)	*puncticollis*
Hymenoptera	Tenthredinidae	Tenthredininae	*Tenthredo (Tenthredopsis)*	*coquebertii*	(Lacourt, 1999)	

and climate change. Besides the effect of climate change on vertical displacement of sawflies, the results showed that biological cycle of some sawfly species was advanced 20–30 days when compared with the dates of their usual presence in 1950–70s.

Climate Change in the Andalusia Region

Processing climatic data from the Andalusia region, it has been found that average temperature and humidity changed in 21st century in comparison to data processed in 20th century.

Changes in Temperature

Analised temperature data showed that averege temperatures in the inteval from 2010 to 2015 increased in comparison with the average tempereatures in the reference period between 1971–2000 (Figs. 2 and 3).

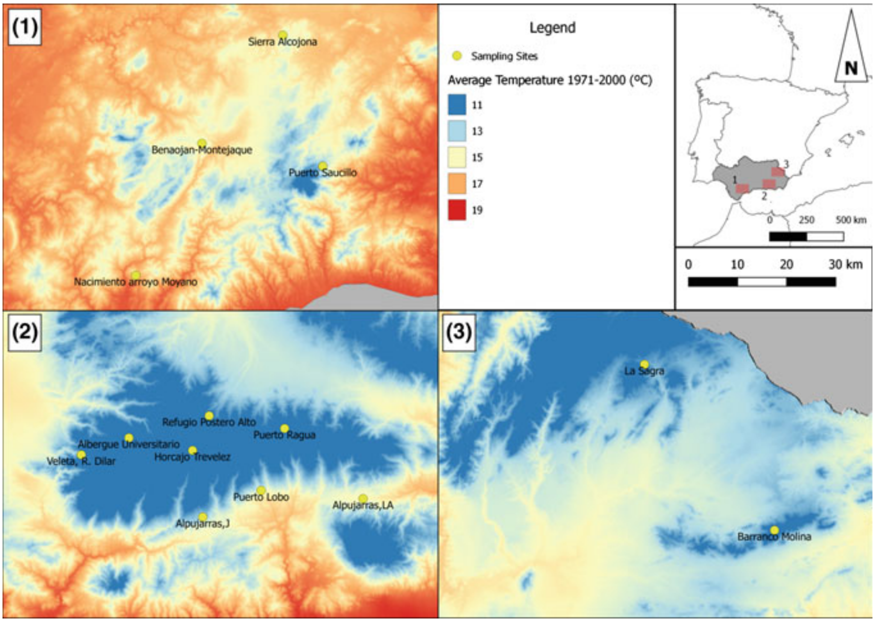

Fig. 2 Average temperatures in the period from 1971 to 2000: (1) Malaga; (2) Sierra Nevada; (3) Alto Guadiana

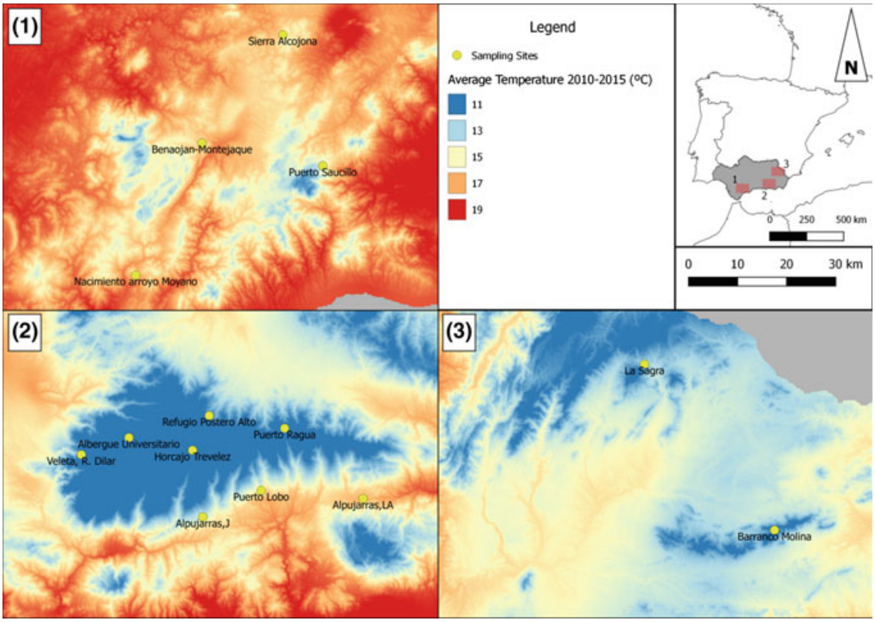

Fig. 3 Average temperatures in the period from 2010 to 2015: (1) Malaga; (2) Sierra Nevada; (3) Alto Guadiana

These changes are specially intense in the lower latitudes of Malaga and Sierra Nevada at low and mid altitudes, and less on the higher altitudes (> ~1500 m.a.s.l.). In particular, higher temperatures rise in valley bottoms, plain and coastal areas, while higher peaks keep similar temperatures.

In the 21st century average temperatures reached 19° in some regions of Malaga and Sierra Nevada (Fig. 3), while in 20th century maximum average temperatures were 17° (Fig. 2).

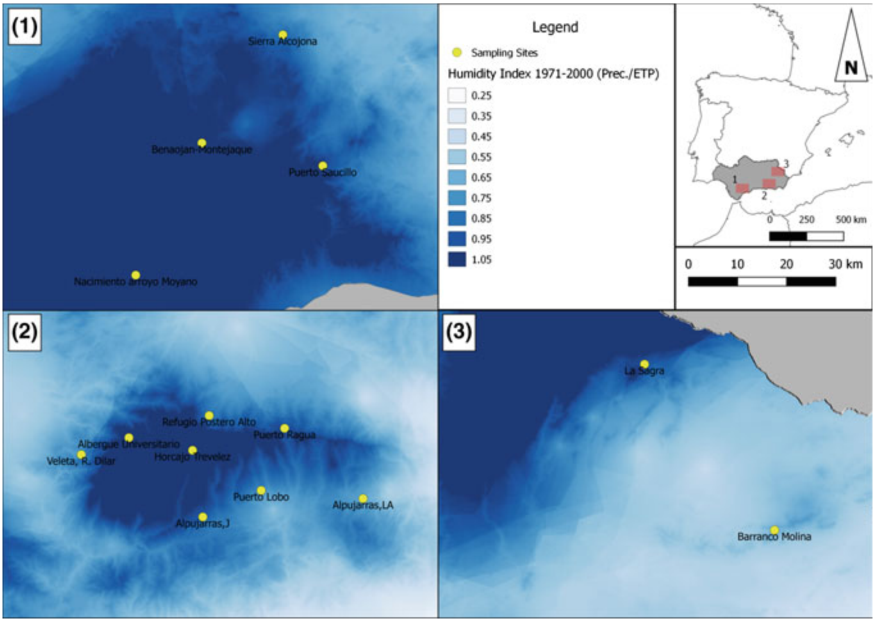

Fig. 4 Average Humidity Index in the period from 1971 to 2000: (1) Malaga; (2) Sierra Nevada; (3) Alto Guadiana

Changes in Humidity

In addition, data showed important changes in humidity (Humidity Index (HI)) between the two periods (Figs. 4 and 5). Humidity Index has been significantly reduced in all study areas. In the maps below (Figs. 4 and 5), these changes in HI have been visually presented, showing changes in different blue tones (dark-blue shows high HI and light-blue low HI). These changes are particularly intense in the oriental sampling sites (Alto Guadiana and Sierra Nevada) at all altitudes, but specially at higher mountanious areas (> ~1500 m.a.s.l.) where humidty shows a clear trend to desertification (HI<1).

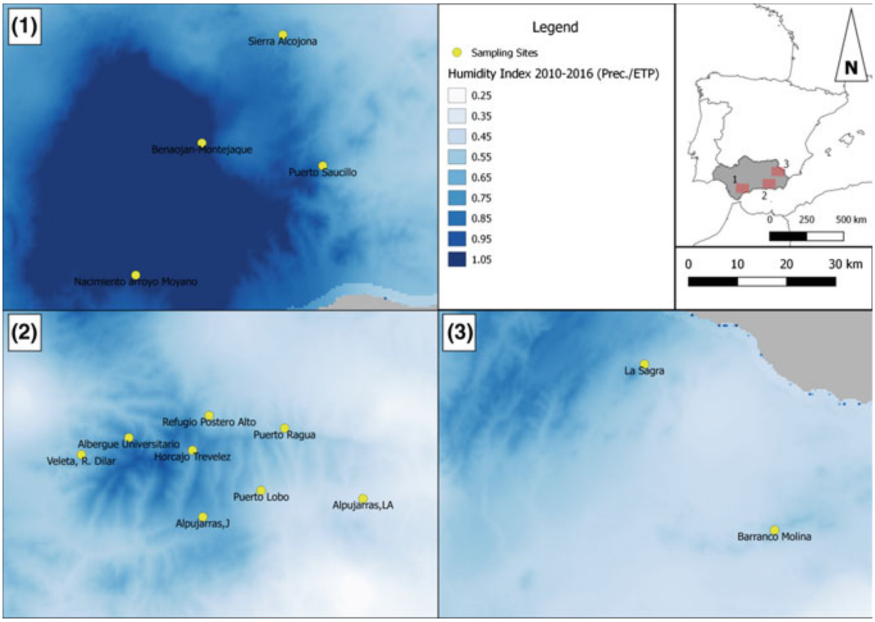

Fig. 5 Average Humidity Index in the period from 2010 to 2015: (1) Malaga; (2) Sierra Nevada; (3) Alto Guadiana

Effect of Changes in Humidity and Temperature on Displacement of Sawflies

In comparison with data from the 20th century, differences in climatic parameters (temperature and humidity) and distribution of sawfly species in studied locations have been found in 21st century (Table 3). The results showed that in some locations number of sawfly species decreased, while in others increased or did not change. In most locations average temperature increased, however in two locations above 2000 m (Veleta and Horcajo Trevelez in Sierra Nevada) and one at 612 m (Nacimiento Arroyo Moyano in Malaga) slightly decreased (Table 3).

In addition, the results showed that HI has been reduced in all sampling locations except Benaoján-Montejaque, Grazalema (Malaga), where it slightly increased (Table 3).

The most significant reduction in HI was noticed in Malaga (Nacimiento Arroyo Moyano) followed by several locations in Sierra Nevada (all above 2000 m).

Therefore, decrease of sawfly species in the same sampling locations could be closely related with changes in climate (decrease in humidity or increase in temperature) (marked in red-Table 3). Nevertheless, the effect of microclimate and/or human activities in each area has a significant role and it can bias the obtained results.

Table 3 Species count differences for each site compared with temperature and humidity index variations between the intervals

	Site	Altitude (m)	Species before 1980	Species after 2010	Difference	Tº dif 2010–2015 1971–2000	HI 2010–2016/1971–2000
Sierra Nevada	Albergue Universitario, Sierra Nevada	2500	4	1	−3	*1.54223*	*−0.45907*
	Veleta, Río Dilar, Sierra Nevada	2500	0	5	5	−0.50809	−0.17531
	Horcajo Trevelez - Srra. Nevada	2176	6	4	−2	−0.21871	*−0.50198*
	Puerto de la Ragua, Sierra Nevada	2041	3	4	1	0.91798	−0.4148
	Refugio Postero Alto, Barranco de Alhorí	1900	1	3	2	0.61558	−0.30692
	Puerto del Lobo, Sierra Nevada	1386	3	1	−2	0.99955	−0.24939
	Alpujarras, J	1255	3	4	1	1.22439	−0.24308
	Alpujarras, LA	804	3	1	−2	*1.63547*	-0.27855
Malaga	Sierra Alcojona	1498	3	3	0	0.57329	−0.15898
	Puerto del Saucillo, Sierra de las Nieves	1200	3	3	0	1.32052	−0.23672
	Nacimiento arroyo Moyano, Sierra de Ronda	612	4	2	−2	−0.1416	*−0.5052*
	Benaoján-Montejaque, Grazalema	524	2	3	1	1.22363	0.16542
Alto Guadiana	Barranco de Molina, Sierra María	1649	3	5	2	0.46915	−0.09233
	La Sagra, Fuente Tornajo	1558	11	10	−1	*1.2768*	*−0.39631*

Table 4 Altitude displacement trends observed for each sawfly species

Genere	Species	Trend	Minimum variation	Maximum variation
Macrophya	***annulata***	observed at higher altitude	324	1888
Tenthredo (Elinora)	***baetica***	observed at lower altitude	−91	−1125
Megalodontes	***bucephalus***	not observed	–	–
Rhogogaster	***chlorosoma***	not affected	0	0
Tenthredo (Tenthredopsis)	***coquebertii***	horizontal displacement	0	0
Corynis	***dusmeti***	not observed at lower altitude	0	588
Dolerus	***germanicus***	not affected	0	0
Dolerus	***anticus***	not affected	0	0
Arge	***melanochroa***	observed at lower altitude	−60	−60
Tenthredo (Cephaledo)	***meridiana***	observed at higher altitude	324	1976
Tenthredo (Eurogaster)	***mesomelas***	migrate, not observed at lower altitude	0	1696
Macrophya	***militaris***	not observed	–	–
Tenthredo (Eurogaster)	***mioceras***	not affected	0	0
Macrophya	***montana***	observed at higher altitude	91	1037
Strongylogaster	***multifasciata***	not observed	–	–
Arge	***ochropus***	not affected	0	0
Rhogogaster (Cytisogaster)	***picta***	observed at higher altitude	392	392
Dolerus (Poodolerus)	***puncticollis***	not observed	–	–
Tenthredo (Tenthredopsis)	***scutellaris***	migrate, observed at lower altitude	0	-851
Abia	***sericea***	migrate to higher altitude	342	1888
Dolerus (Achaetoprion)	***uliginosus***	not affected	0	0
Tenthredo	***violettae***	migrate to higher altitude	824	959

Table 5 Summary of species and trends based on vertical and horizontal displacement

Trend	Number of species	%
Vertical displacement (observed at higher/not observed at lower altitude)	8	36
Vertical displacement (observed at lower altitude)	3	14
Horizontal displacement	1	5
Not affected	6	27
Not observed on 21st century (disappeared)	4	18
Total	22	100

For that reason, only vertical displacement (observed at higher/lower altitude) was closely related with climate change.

Vertical Displacement of Sawfly Species

Six species (*Arge ochropus, Dolerus germanicus*, *Dolerus (Achaetoprion) uliginosus, Dolerus anticus, Rhogogaster chlorosoma, Tenthredo mioceras*) were not affected, and they maintained their habitats in the same locations as in the 20th century (Table 4). On the other side, the results of this study showed that six of the sawfly species migrated to higher and three to lower locations. Only one species (*Tenthredo coquebertii*) migrated to other locations but without changing the altitude (horizontal displacement), while two species (*Corynis dusmeti* and *Tenthredo mesomelas*) disappeared from lower altitude and were detected only at higher altitudes (Table 4).

The most important findings of this study showed that in transects conducted in the 21st century four species (*Megalodontes bucephalus, Macrophya militaris, Strongylogaster multifasciata, Dolerus (Poodolerus) puncticollis*) were not observed in any location nor sampling area (Table 4), meaning that these species are not present anymore in the Andalusia region.

Data presented in Table 4 was summarized in Table 5, showing that 36% of sawfly species migrated to higher locations, only 14% to lower locations, while 18% of the species disappeared from the study area. The results also showed that 27% of the species were not affected by altitude or climatic conditions (Table 5) and they maintained present in the same locations as 50–80 years ago. In addition, only 5% (one species) displaced horizontally, probably caused by changes in habitat provoked by human activity.

Discussion

Changes in temperatures affect biological cycle of sawflies, forcing them to migrate, adapt to present conditions or in worst cases to face extinction. Changing climate affects ecosystems since warming may force species to migrate to higher latitudes where temperatures are more favourable for their survival. In this study, of twenty-two sawfly species found in the 20th century only eighteen species were re-found in the 21st century in the Andalusia region. Although all initial locations were trans-crossed again in 21st century, the data of this study showed that 4 sawfly species disappeared from the study area.

In addition, the results showed important vertical and horizontal displacements of sawflies to different locations. This was especially observed in sawfly species with narrow temperature optima, since they are highly affected with climate change (Sholes 2011). Similar findings have been proven for other insects, as for example, migration of pollinators was described by Scaven and Rafferty (2013) or adaptation of different herbivores to changes in climate in Gutbrodt et al. (2011). Regarding sawflies, only the most important sawfly pests were studied in depth e.g. wheat stem sawfly (Perez-Mendoza and Weaver 2006), apple sawfly (Graf et al. 2001), pine sawfly (Sholes 2011). However, this study was focused on all sawfly species detected in the study area and the results of cross-transects showed that none of the species in that area is pest to horticultural or forest crops. In contrary, the sawflies studied are beneficial since they are natural pollinators of the plants where they grow and feed, contributing in maintenance of the botanical biodiversity of landscapes. For that reason, disappearance of sawfly species in the study area can provoke changes at many levels.

Most of the studied sawflies are insects adapted to warm environments with high degree of humidity, usually coinciding with the emergence of adults with the flowering of a large number of weeds that will provide them with the necessary proteins for their feeding (pollen) as well as the essential sugars (nectar). For that reason, decrease in humidity might be the more important trigger for sawfly displacement than elevated temperature in the 21st century.

Although vertical displacement (migration of species to higher or lower latitudes) is mainly related with changes in climate, horizontal displacement can frequently be provoked by human activities, changes in habitat or landscape etc. Man alters the landscapes by reducing some of the meadows to expand crops or forest plantations (mainly pine trees), or to extend ski slopes at the Sierra Nevada (Aguado Martin 2016). All this has reduced and fragmented some habitats and affected the survival of some species in a very negative way, especially for some sawfly species (e.g. *Corynis*, *Dolerus* and *Megalodonts*) which have low rate of mobility (they are able to move only between 40 and 100 meters from the place they were born) (Aguado Martin 2016).

Among the species studied, the most sensitive ones, both for their nutritional specialization and for their habitats, are *Megalodontes bucephalus* and *Corynis dusmeti*, both related to plants of the genus *Ranunculus*, in which their larvae feed and adults feed and mate. These plants begin to be scarce in some areas, so these species must so follow water streams to avoid dehydration and survive, or they must fly to wooded areas (pine forests, pins pares, underbrush) where these flowers keep growing (Aguado Martin 2016). One of the species that disappeared, *Strongylogaster multifasciata* is linked in the areas studied to the presence of ferns, but these plants have drastically reduced their habitat. In addition, the maximum temperatures start to be almost insurmountable for the development of their larvae.

Disappearance of *Dolerus puncticollis* cannot be found in its nutritional plants (grasses), since these survive in the study area, but rather in the temperature thresholds too high, since it is a very sensitive to high temperatures and they also need a high humidity for survival.

Finally, *Macrophya milittaris* (species usually lives only in cool and shady areas and close to riverbank forests or water courses) was not found in 21st century, since changes in climate affected vegetation drastically. Its disappearance since 1952 is quite striking and it has been telling us how climate change in the south of the Iberian Peninsula has been occurring for many decades in a slow and progressive but unstoppable way. This study showed that climatic change caused disappearance and migration of some sawfly species, while others were negatively affected with human activity. The main limitation of this study is low number of repetitive observation in the second observation period. For that reason, it is highly recommended to conduct similar studies in the future, in order to obtain complete image of what is causing the displacements of sawfly populations in the Andalusia Region and to find the most sustainable way how to mitigate it.

Conclusions

Evaluating the most important climatic parameters, humidity and temperature, have been observed that climate changed in the last 100 years in the study area (Andalusia region, Spain). In many locations of this study, average temperature increased and humidity index decreased. These changes can affect survival of many species in their natural habitat. The study showed that in some locations number of sawfly species decreased while in others increased or did not change. In addition, some of the sawfly species migrated to higher or lower locations, while others migrated to other locations but without changing the altitude. The study showed that in the 21st century four species (*Megalodontes bucephalus, Macrophya militaris, Strongylogaster multifasciata, Dolerus (Poodolerus) puncticollis*) were not observed in any location nor sampling area, meaning that these species are not anymore present in the Andalusia region. In conclusion, changes in climate affected vertical displacements of different sawfly species as well as disappearance of four sawfly species in Andalusia region.

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Coffee, Climate and Biodiversity: Understanding the Carbon Stocks of the Shade Coffee Production System of India

Nadesa Panicker Anil Kumar, Amsad Ibrahim Khan Saleem Khan and Vaniyan Balakrishnan

Abstract In the light of climate change, the ecosystem services of traditionally maintained shaded Arabica coffee farms become prominent largely for increasing carbon removal. The most important function of the shade-grown coffee **agroforestry** system is the reduction of **the** concentration of Carbon in the atmosphere. It is estimated that one-hectare shade-grown coffee farm with large forest trees can sequester 70–80 tonnes of carbon per hectare, which is more or less equivalent to the carbon stored in **an** equal area of forest. A **full** sun–grown or open coffee in one hectare can only store less than 10 tonnes of carbon. "Monsooned Malabar Arabica Coffee is a specialty coffee of India, sourced from shade coffee plantation and has geographical indication (GI) protection. Shade grown coffee also serves as a refuge for biodiversity and its diverse and complex structure has a high potential to retain biodiversity in the changing climate scenarios. In this context, this paper discusses the nexus of coffee, climate and biodiversity and its implications with Wayanad, Kerala, India as a case study. This paper emphasizes the need for promoting sustainable production and consumption of coffee as a carbon neutral brand and promotion of shade grown, biodiversity rich and climate resilient coffee can emerge as a **highly valued** com-

N. P. Anil Kumar (✉) · A. I. K. Saleem Khan
M. S. Swaminathan Research Foundation, 3rd Cross Street, Taramani Institutional Area, Chennai 600 113, India
e-mail: anil@mssrf.res.in; anilmaruthur@gmail.com

A. I. K. Saleem Khan
e-mail: saleemkhan@mssrf.res.in; asaleemkhan.cc@gmail.com

V. Balakrishnan
M. S. Swaminathan Research Foundation, Puthurvayal P.O, Wayanad, Kalpetta, Kerala 673577, India
e-mail: balakrishnan@mssrf.res.in

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modity in **the** world coffee market. Attempts **at** revival of the shade grown coffee system amongst the small growers with appropriate steps in marketing the coffee as a **specialty** product (carbon neutral and grown in bio-diverse environment) are discussed.

Introduction

The Paris agreement on climate change strengthens the global response to the threat of **a** changing climate by keeping a global temperature rise this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C (UNFCCC 2017). Therefore, keeping global temperature below the estimated level by reducing GHG in the atmosphere is essential. Removing atmospheric carbon and storing it in the terrestrial biosphere is one of the options, which have been proposed to compensate GHG emissions (Albrecht and Kandji 2003). The importance of agroforestry systems as carbon sinks has recently been recognized due to the need of climate change mitigation (Soto-Pinto et al. 2010). It is also considered as an option aimed at reducing **emissions** of greenhouse gases in the United Nations based REDD+(reducing emissions from deforestation and forest degradation, conserving and enhancing forest carbon stocks, and sustainably managing forests) program for tropical developing regions (Atangana et al. 2014; Tumwebaze and Byakagaba 2016). It has the potential to sequester atmospheric carbon in trees and soil while maintaining sustainable productivity (Oelbermann et al. 2004). It can mitigate GHG emissions, conserve biodiversity and generate income (Hager 2012). Given that the most significant increases in carbon storage on land can be achieved by moving from low-biomass, land-use systems to tree-based systems, the practice of agroforestry presents a viable option for forest-based mitigation (Polzot 2004).

Coffee agroforestry has emerged as a promising land use system for sequestering carbon and contributing to climate change mitigation (Dossa et al. 2008; Soto-Pinto et al. 2010; Schmitt-Harsh et al. 2012). Given enhanced carbon sequestration that occurs with tree planting and the practice of agroforestry farming, shade grown coffee systems have been recognized as viable afforestation and reforestation (A&R) strategies under the Clean Development Mechanism (CDM) of the Kyoto Protocol (IPCC 2000; UNFCCC 2006; Schmitt-Harsh et al. 2012). Compared to non- shaded or partially shaded plantations, shade-grown coffee stores significant amounts of carbon in both the aboveground woody biomass of shade trees and the litter layer and soil organic matter. These pools contribute to GHG emission reductions and the alleviation of GHG accumulation in the atmosphere (Polzot 2004). On the other hand, coffee is cultivated under a canopy of shade trees, a practice that ensures the longevity of the farm, supports biodiversity, and provides communities with a broad array of ecosystem services (Jha et al. 2011). *Coffea arabica* is grown under the shade of trees, which moderate the microclimate for the benefit of the crop (Van Kanten and Vaast 2006; Siles et al. 2010; Hergoualch et al. 2012). Moderately shaded *Coffea arabica* coffee plants have photosynthetic rates three times higher than coffee leaves under full sun and planting *Coffea arabica* under shade is the most important for both quality improvement and maintaining sustainable production (Alemu and Dufera 2017). Recent studies in traditional shaded coffee plantations have demonstrated this agroecosystem's potential as a refuge for biodiversity (Perfecto et al. 1996; Moguel and Toledo 1999; Perfecto et al. 2003). Shade grown coffee plantation has diverse, complex structure and that has a high potential to retain biodiversity in the changing climate scenarios. However, researches in coffee systems **have** allowed for an improved understanding of habitat management and biodiversity, a closer examination of the relationships between biodiversity and ecosystem services (Jha et al. 2014), and a greater understanding **of** the linkage between climate change and biodiversity. Thus, densely shaded coffee agroforests besides demonstrable carbon benefits, it also provides a number of other ecosystem services and functions (e.g. soil conservation, water regulation) similar to natural forest ecosystems (Schmitt-Harsh et al. 2012). Shaded coffee provides a viable business case to coffee smallholders and supports biodiversity and ecosystem services. Besides the direct benefits to small-scale coffee farmers, further opportunities to increase the attractiveness of shaded plantations may lie in ecosystem services related to shade trees (Jezeer and Verweij 2015). While the ecological and socioeconomic costs and benefits associated with shade coffee are clear, many modern management schemes abandon shade practices and also there are many challenges **in** bridging sustainable coffee management with livelihood security (Jha et al. 2011). Importantly, biodiversity declines within coffee systems are of particular concern, given that ecosystem services such as pollination, pest control, erosion control, watershed management, and carbon sequestration are worth billions annually and are largely a function of biodiversity levels (Wardle et al. 2011; Jha et al. 2014).

Thus, the rationale behind this paper is to develop a holistic understanding of a comprehensive approach to study carbon benefits, conserve biodiversity, and sustain ecosystem services of **the** shade-grown coffee system in the face of climate change. The objective of this paper is to discuss that the shade-grown coffee has a high potential for carbon storage, studying its carbon profile and promoting their application as a significant climate change adaptation and mitigation strategies to conserve biodiversity and to sustain ecosystem services in the Indian context. It is also to highlight the value of Shade Coffee System **in the** conservation of quite a good number of threatened tree species of Western Ghats (a global biodiversity hotspot), which are in use as the source of products such as timber, fruits, nuts, resins and gums or barks. In this paper, we have taken Wayanad District of Kerala in India as a case study and we outlined the shade-grown coffee through the lens of climate change and biodiversity. We have also discussed the difference between traditional shade and modern open system and highlighted the nexus of carbon stock of coffee production system and biodiversity. Importantly, we emphasized the need for promoting sustainable production and consumption as a carbon neutral coffee brand and accentuate that shade grown, biodiversity rich and climate resilient coffee can emerge as a high**ly** value**d** commodity in **the** world coffee market.

Coffee, Climate, and Biodiversity of Wayanad, Kerala

Wayanad is a highland region with altitudes ranging from 700 to 2100 m above sea-level and a district in the southern state of Kerala in India that enjoys a unique local climate and culture (Fig. 1). Major climate trends observed in Wayanad include rising minimum temperatures, weakening in the early phase of the south-west monsoon precipitation; **the** increasing polari**z**ation of daily rainfall and more frequent heavy rainfall days (Srinath and Kumar 2012). Thus, it has a hot and humid climate, with **a** minimum temperature ranging from 14 to 20 °C, maximum 25–32 °C. Because of abundant sun and rainfall (2000–3000 mm per year, spread out over 10 months), this is **a** highly fertile land (Fransen 2009). The topography of Wayanad described is responsible for a unique climate in Wayanad that is quite distinct from the climate of neighboring regions. It is responsible for a strong gradient in rainfall within the district as well. The primary rainfall season of the region is during the south-west monsoon period (Kumar and Srinath 2011).

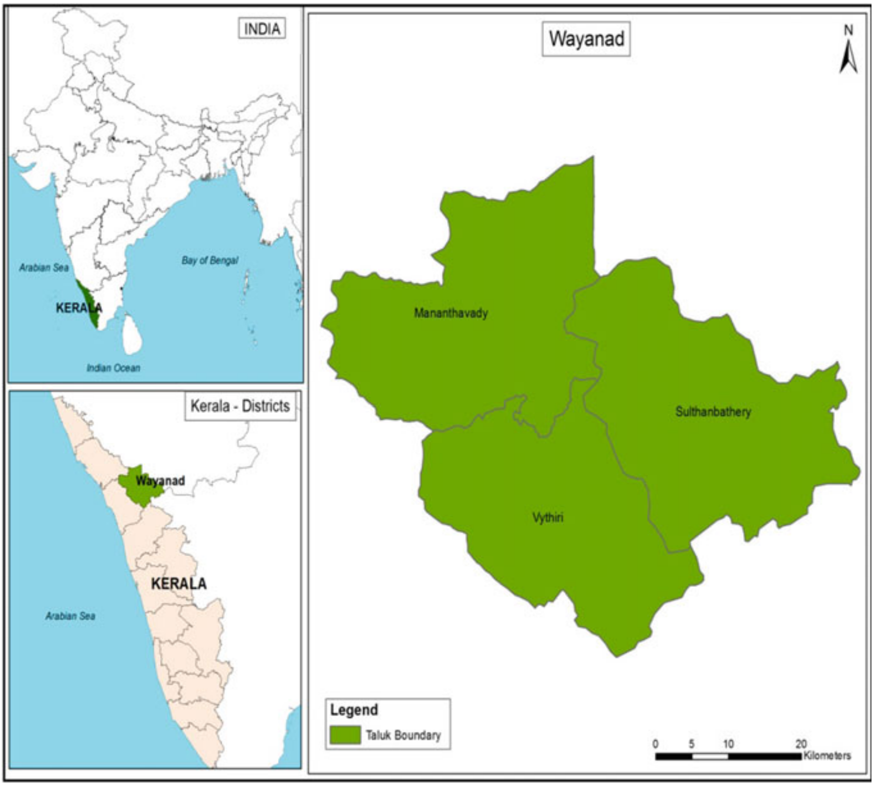


Fig. 1 Map of the study area—Wayanad, Kerala, India

Wayanad is declared as one of the 18 true agro biodiversity hotspots in the world (Joy 2004). Wayanad-Silent Valley region in the Western Ghats is a global biodiversity hotspot. This region is climate vulnerable in terms of scores of factors like (i) higher variation in rainfall, (ii) chances of flash floods and prolonged droughts, (iii) increased occurrences of forest fire, (iv) landslide, (v) unscientific land use pattern, (vi) erosion of biodiversity, (vii) concentration of tribal communities and landless people, (viii) lower ranking in the human development index and higher social deprivation and environmentally fragile landscapes, and (ix) high percentage of **the** population of small holder farmers who rely on rain-fed agriculture.

Today it is home to a complex agro-forestry economy where major plantation crops such as coffee, pepper and tea along with crops such as rice and banana, along with a host of others are grown intensively at multiple times in the year. Wayanad is also home to a large tribal population (17.43% of **the** total population as per Census 2001) who are socio-economically worse off compared to the general populace. Apart from the general climate-dependent nature of the economy, the small size of land-holdings of most farmers in Wayanad and the larges**t** tribal population renders the people and the livelihoods of Wayanad highly vulnerable to climate change and variability (Srinath and Kumar 2012).

Coffee is one of the important plantation crops of India, which is cultivated mainly in the hill tracts of South India especially in Karnataka, Kerala, and Tamil Nadu. The other important States of India in which coffee is grown on a limited scale are Andhra Pradesh, Maharashtra, West Bengal, Assam, Andaman and Nicobar Islands, and Madhya Pradesh (Joy 2004). Kerala is the second largest producer of coffee in India. It produces 23% of the total coffee output in the country. Wayanad produces 90% of the total coffee output in the State (Joy 2004). Of the territory of Wayanad, 54% is agriculture land, 37% is forest. The main product is coffee and it occupies 110,000 ha, 58% of the total agricultural land in the district. 80% of total coffee in Kerala **are** from Wayanad (Fransen 2009). The district is rich in agrobiodiversity though on-farm erosion of genetic diversity of crops, breeds and strains are reported high in the region (Kumar et al. 2010, 2015).

The wild biodiversity of Wayanad is also very rich both in terms of species, genera, families, and high percentage of endemism (MSSRF 2016). The area of Wayanad falls entirely within the Western Ghats of India, which was one of the eighteen biodiversity hot spots proposed originally by Myers (Myers et al. 2000; Santhoshkumar and Ichikawa 2010). The forests here are globally important as they house endemic flora and fauna, which include 229 species of plants, 31 species of mammals, 15 species of birds, 52 species of amphibians. Among these, 55 species are critically endangered, 148 species are endangered and 129 species are vulnerable as per IUCN classification. Moreover, a number of cultivated food plants have their wild relatives in these forests. Among spices, black pepper, cardamom, cinnamon and curcuma have their wild relatives largely in these wet evergreen forests (Santhoshkumar and Ichikawa 2010).

Coffee Cultivation: Traditional Shade and Modern Open System

Coffee cultivation provides livelihoods for a large number of people live in the biodiversity-rich mountainous states of India like Wayanad, Kerala. Coffee (*Coffea arabica* (de Jessieu) Linn) was introduced in India about 400 years ago in **the** *Baba Budan* hills in the Western Ghats, which presently a global biodiversity hotspot. India's wild coffee species are *C. bengalensis, C. travancorensis, C. wightiana, C.khasiana* and *C.jenkinsii.* Amongst these species the first three were conventionally placed under the genus *Psilanthus*, but of late all being treated as species of the genus *Coffea*. *Coffea robusta* L (*C. canephora* Pierre ex A froehner) and the varieties like Cauvery, S.795, and Sln 9 which perform well in a broad range of shade (30–60%) are becoming the preferred choices in the major coffee grown regions of India. Figure 2a and b represents shade coffee farms and open or partially shaded coffee farm in Wayanad District of Kerala, India. Though Coffee is considered as one of the major agricultural commodities that drive deforestation, the traditional farming methods of the small coffee growers in India were on the contrary to this belief. Since 1840 the British popularized coffee cultivation on a plantation mode in selectively cleared evergreen and moist-evergreen forest slopes of the medium elevation mountains, mainly in **the** south west and eastern region of India, in three states Karnataka, Kerala and Tamil Nadu. Now Coffee plantations being spread in the north eastern hill regions of the country too. Till early part of 1990s "Arabica coffee" dominated the coffee plantation. The dominance of Arabica has been falling down for the last 20–25 years with the preference over the Robusta variety-a sturdy, high yielding and sun-loving species. Now, nearly 80% of the Coffee plantations in Karnataka and Kerala dominated by the Robusta variety. Another variety that is grown in the region, but not for commercial purpose is Liberian Coffee (*Coffee liberica*).

Presently, three different kinds of structural designs for growing coffee (Arabica and Robusta coffee) have been seen, such as (i) substantially shaded ones (purely Arabica) integrated with large forest trees, which are mainly for growing black pepper, and ground cover of ginger, clove and turmeric. This practice is mostly followed by the small scale farmers as an income security strategy by having multiple crops (ii) medium shaded farms (both Arabica and Robusta) with predominantly jack trees or the exotic silver oak trees integrated with pepper and ginger, or turmeric as ground crops; and (iii) un-shaded or open mono crop farms with only Robusta. The predominant trend amongst the big planters of the region, is maintaining Robusta mono-crop coffee farms in view of getting the maximum production from the target crop. The research and development (R&D) system of the country gives more focus on only increasing the total production and productivity of the coffee. Thus, this system of production of coffee is getting popularized, and it is destructive to biodiversity and many of the beneficial ecosystem services (Kumar 2017).

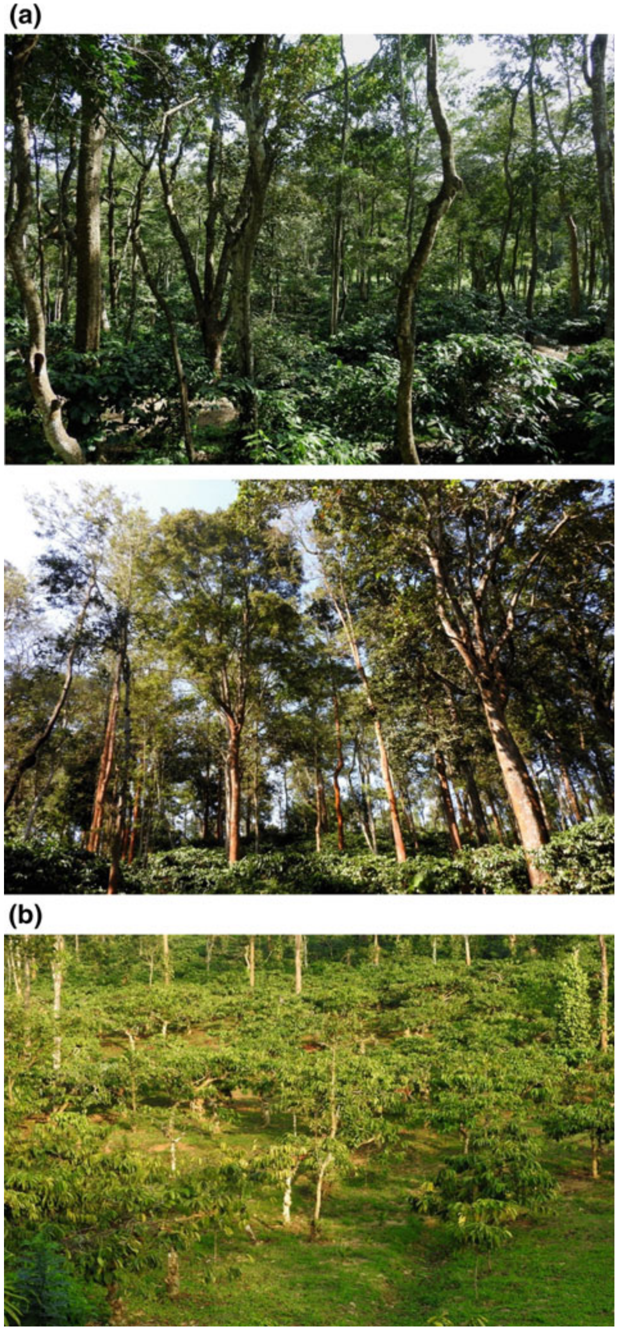


Fig. 2 **a** Shade coffee farms, Wayanad, Kerala, India. **b** Open or partially shaded Coffee Farm, Wayanad, Kerala, India

Shade Grown Coffee System Is Akin to Tropical Forest

Coffee is shade tolerant and traditionally grown under shade trees in complex agroforestry systems, thereby providing a refuge for biodiversity and sustaining other ecosystem services. Shade grown coffee is increasingly promoted as a promising approach to deal with the twin challenges of biodiversity conservation and local development. Biodiversity benefits associated with shaded coffee practices are well researched and it is clear that these systems hold considerable potential to conserve biodiversity (Bhagwat et al. 2008; Jezeer and Verweij 2015). The shade grown coffee forestry system has many features and functions of a tropical forest ecosystem. For example, many such farms are ground water recharging catchments and playing a key role in **the** maintenance of the local hydrological systems (Kumar 2017). Habitat on shade-grown coffee farms outshone sun-grown coffee farms with increased numbers and species of birds as well as **an** improved bird habitat, soil protection/erosion control, carbon sequestration, natural pest control and improved pollination. While sun-grown systems can have higher yields, the shaded farms easily outperform them in sustainability measurements with the trees providing an array of ecological services that offer both direct and indirect "income/payback" to farmers and the environment (Rice 2010). Shaded coffee provides a viable business case to coffee smallholders. Besides the direct benefits to small-scale coffee farmers, shade trees provide a sustainable and financially viable strategy to cope with climate and payments for ecosystem service (e.g. carbon sequestration) can increase farmer s' incomes (Jezeer and Verweji 2015).

Some large shaded coffee farms in Wayanad district of Kerala were identified with 85 different forest tree species (Table 1), the frog species diversity is also immensely rich in shade coffee farms, which include 10 rare and threatened frog species (Ground Frog (1sp) Bush Frog (6 spp) and tree frog (3 spp). Out of this 9 species, six are recently described new species (Refer Box. 1). Figure 3 showcases some of the frog diversity identified from the shade coffee farms of Wayanad, Kerala. *Pseudophilatus wayanadensis* is a mid-elevation species inhabiting leaf litter and shrubs and commonly seen in the coffee plantations. Males are found calling from the top of the coffee plants at an average heigt of 1.5 m the ground. Eggs laid in the soil under leaf litter (Jerdon 1854; Biju et al. 2010); *Raorchestes anili* is a mid-elevation species inhabiting thick bushes, preferring shady canopy areas of coffee plantation. Vocalising males with their distinct metallic "ting-ting-ting" calls are found during late may to early October on the foliage up to 3 m and eggs are laid in the soil under leaf litter (Biju and Bossuyt 2006; Biju et al. 2010); *Raorchestes akroparallagii* is a low-mid elevation species having a wide distribution in the Western Ghats. Males are found calling from bushes at a height of 1–2 m from the ground. Various **color** morphs ranging brown to yellow **colors** are observed within this species (Biju and Bossuyt 2009; Biju et al. 2010). Details of information about other frog species are presented in the Box. 1. Furthermore, over 80 bird species, more than in an equivalent area of open coffee land, and exceeded only by primary tropical forest also reported from this "semi-forest" plantation type. The shades coffee forestry system with reference

Table 1 List of tree species found in shade coffee plantations of Wayanad

Sl. No	Botanical name	Local name
1.	*Holigarna arnottiana*	Cheru
2.	*Holigarna grahamii*	Cheru
3.	*Mangifera indica*	Moochi
4.	*Spondias pinnata*	Kattu Ambazham
5.	*Cananga odorata*	Langilangi
6.	*Polyalthia coffeoides*	Nedunar
7.	*Alstonia scholaris*	Ezhilam Pala
8.	*Tabernaemontana alternifolia*	Kundala Pala
9.	*Wrightia arborea*	Mylam Pala
10.	*Caryota urens*	Aanapana
11.	*Vernonia arborea*	Karana
12.	*Oroxylum indicum*	Palakapayyani
13.	*Spathodea campanulata*	Thaneerkaimaram
14.	*Stereospermum colais*	Pathiri
15.	*Lophopetalum wightianum*	Venkkotta
16.	*Garcinia gummi-gutta*	Kodampuli
17.	*Terminalia bellirica*	Thanni
18.	*Terminalia paniculata*	Maruthu
19.	*Dillenia bracteata*	Kattupunna
20.	*Vateria indica*	Payin
21.	*Elaeocarpus serratus*	Kara
22.	*Elaeocarpus tuberculatus*	Mukkanni
23.	*Antidesma montanum*	Putharaval
24.	*Aporosa cardiosperma*	Vetti
25.	*Croton tiglium*	Neervala Maram
26.	*Glochidion ellipticum*	Njanjetti
27.	*Macaranga peltata*	Vatta
28.	*Mallotus philippensis*	Sindooram
29.	*Phyllanthus emblica*	Nelli
30.	*Bischofia javanica.*	Neeli
31.	*Acrocarpus fraxinifolius*	Nari Venga
32.	*Cassia fistula*	Kanikkonna
33.	*Adenanthera pavonina*	Manchadi
34.	*Albizia amara*	Nenmen ivaka
35.	*Albizia lebbeck*	Vaka
36.	*Butea monosperma*	Plasu

(continued)

Table 1 (continued)

Sl. No	Botanical name	Local name
37.	*Dalbergia latifolia.*	Veeti
38.	*Flacourtia montana.*	Chalir Pazham
39.	*Hydnocarpus pentandra*	Marotti
40.	*Scolopia crenata*	Mullukara
41.	*Nothapodytes nimmoniana*	Peenari
42.	*Actinodaphne malabarica*	Malavirinji
43.	*Cinnamomum malabatrum*	Karuppa
44.	*Cinnamomum wightii*	Kattukaruva
45.	*Litsea coriacea*	Vettithali
46.	*Litsea wightiana*	Pattuthali
47.	*Persea macrantha*	Kulirmavu
48.	*Careya arborea*	Pezhu
49.	*Magnolia champaca*	Chembakam
50.	*Kydia calycina*	Vellachadachi
51.	*Aglaia barberi*	Kara Akil
52.	*Aphanamixis polystachya*	Chemmaram
53.	*Chukrasia tabularis*	Chuvanna Akil
54.	*Melia dubia*	Kattuveppu
55.	*Toona ciliata*	Vembu
56.	*Artocarpus gomezianus*	Pulichakka
57.	*Artocarpus heterophyllus*	Plavu
58.	*Artocarpus hirsutus*	Anjili
59.	*Ficus drupacea*	Kallal
60.	*Ficus exasperata*	Paarakam
61.	*Ficus hispida*	Paarakam Valuthu
62.	*Ficus racemosa*	Atthi
63.	*Myristica beddomei*	Kattu Jathi
64.	*Psidium guajava*	Pera
65.	*Syzygium caryophyllatum*	Njara
66.	*Syzygium cumini*	Njaval
67.	*Chionanthus mala-elengi*	Kalledala
68.	*Olea dioica*	Edala
69.	*Carallia brachiata*	Venkana
70.	*Prunus ceylanica*	Nai kambagam
71.	*Pavetta indica var. tomentosa*	Pavetta
72.	*Acronychia pedunculata*	Muttanari
73.	*Melicope lunu-ankenda*	Kambili

(continued)

Table 1 (continued)

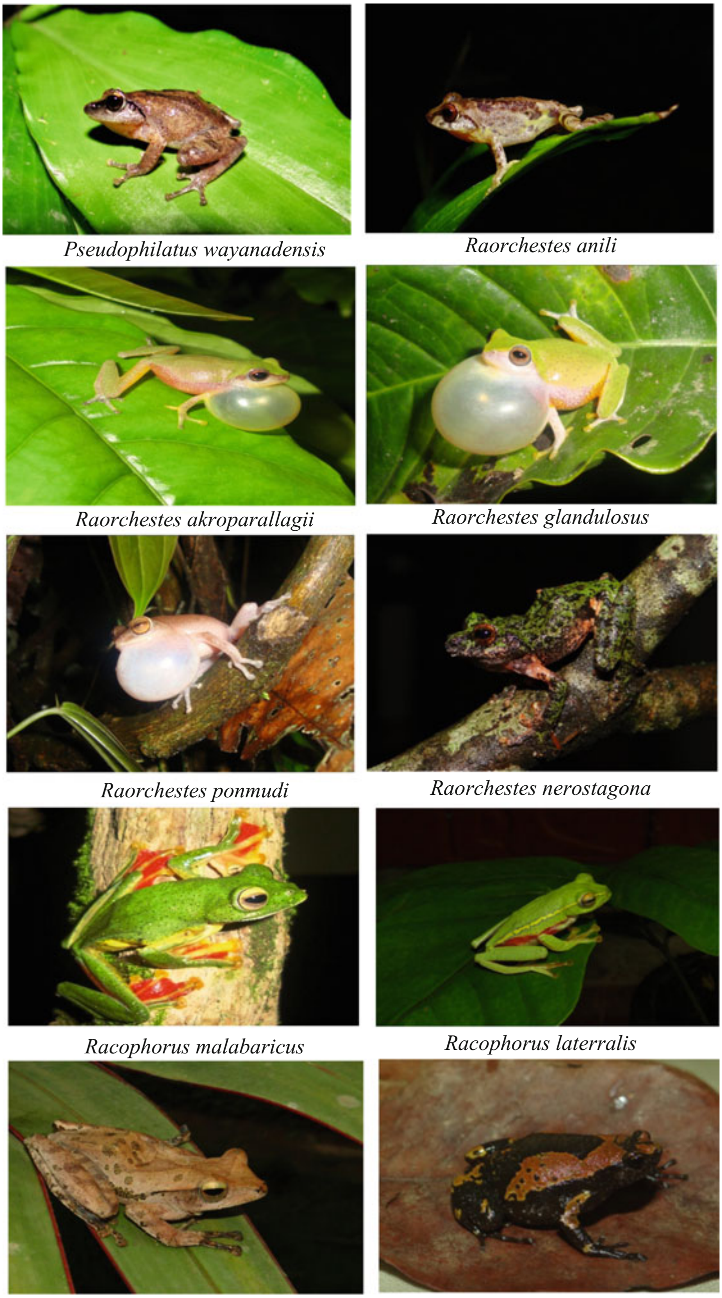
Sl. No	Botanical name	Local name
74.	*Meliosma pinnata*	Kalavi
75.	*Chrysophyllum roxburghii*	Athappala
76.	*Pterospermum diversifolium*	Pambaram
77.	*Sterculia guttata*	Potta-kavalam
78.	*Symplocos cochinchinensis*	Pachotti
79.	*Grewia serrulata*	Kotti maram
80.	*Grewia tiliifolia*	Chadachi
81.	*Celtis tetrandra*	Karukkuyyan
82.	*Celtis timorensis*	Bhoonari
83.	*Clerodendrum infortunatum.*	Peruku
84.	*Gmelina arborea*	Kumbil, Kumizhu
85.	*Vitex altissima*	Myila, Myilu

to earthworms, termites, and ants show the soil of such farms are amazing diverse. (Tables 2, 3 and 4). The traditional integrated coffee farms of the small and marginal farmers are rich in forest tree species and spices like black pepper (of many varieties and species), which are **growing** on the wild trees. The wild pepper species seen are *Piper argyrophyllum* Miq. *Piper attenuatum* Ham., *Piper hymenophyllum* Miq and *Piper wightii* Miq., An endemic wild cinnamon, *Cinnamomum malabatrum* (Burm. f.) Blume; wild turmeric like *Curcuma neilgherrensis* Wight, *Curcuma pseudomontana* Graham, *Curcuma raktakanta* Mangaly & Sabu, and wild ginger such as *Zingiber capitatum* Roxb.,var. *elatum* (Roxb.) Baker, *Zingiber zerumbet* (L.) J.E. Smith, are the species that can common in a shade coffee farm in the district.

Farmers cultivate spices like black pepper, cardamom, cinnamon, clove, ginger and turmeric as the intercrops of the coffee farm. The farms, especially the small farms also are integrated with **the** cultivation of areca nut, and species, like ginger and turmeric (Kumar 2017). Wayanad is a globally renowned region for its exclusive peculiarity and uniqueness in harboring an enormous assemblage of diverse spice crops, among which Wayanadan pepper has got place of pride in international market, because of its unique quality. The district's coffee farms once harbored a wide range of endemic pepper varieties which grew luxuriantly, yielded well and fairly paid the farmers. There are 25 odd pepper varieties being cultivated in the district, mostly as the intercrop of coffee farms (Table 5). Over the last 150 years this method of cultivation has been evolved **into** a sustainable, disease and pest free coffee agro-forestry system (CAS).

Box. 1 The frog diversity identified from shade Coffee Farms of Wayanad, Kerala, India

1. ***Pseudophilatus wayanadensis*** is a mid-elevation species inhabiting leaf litter and shrubs and commonly seen in the coffee plantations. Males are found calling from the top of the coffee plants at an average height of 1.5 m the ground. Eggs laid in the soil under leaf litter (Jerdon 1854; Biju et al. 2010).
2. ***Raorchestes anili*** is a mid elevation species inhabiting thick bushes, preferring shady canopy areas of coffee plantation. Vocalising males with their distinct metallic "ting-ting-ting" calls are found during late May to early October on the foliage up to 3 m and eggs are laid in the soil under leaf litter (Biju and Bossuyt 2006; Biju et al. 2010).
3. ***Raorchestes akroparallagii*** is a low-mid elevation species having a wide distribution in the Western Ghats. Males are found calling from bushes at a height of 1–2 m from the ground. Various colour morphs ranging brown to yellow colours are observed within this species (Biju and Bossuyt 2009; Biju et al. 2010).
4. ***Raorchestes glandulosus*** is a high elevation species distributed above 800 m above sea level. Males are found calling at a height of 3–4 m from the coffee plantations (Jerdon 1854; Biju et al. 2010).
5. ***Raorchestes ponmudi*** is a widely distributed species commonly found in the coffee plantations. Males are observed calling from the leaves and branches of coffee plants and small trees up to 3 m in height. During the winter, several individuals can be found hibernating in tree holes (Biju and Bossuyt 2005a; Biju et al. 2010).
6. ***Raorchestes neros***tagona is a tree dwelling species found in the coffee plantations of Wayanad. The cryptic lichen like colour pattern, provides excellent camoflage from predators. Generally they found on the ground during the non breeding season. However, during breeding season, males climbing to the upper canopy of tall trees to advertise their presence (Biju and Bossuyt 2005b; Biju et al. 2010).
7. ***Racophorus malabaricus*** is a rain forest adopted canopy species commonly seen in the coffee plantations. Build foam nest in water tanks of the coffee plantations (Jerdon 1870).
8. ***Racophorus laterralis*** is a mid-elevation species breed in the water tanks of coffee plantations (Boulenger 1883).
9. ***Polypedates pseudocruciger*** is a low and mid-elevation species found in the wooded areas. Found abundantly in the coffee plantations (Daniels and Ravichandran 1995).
10. ***Uperdon triangularis*** is seen in the leaf litter of coffee plantations and evergreen patches of Western Ghats (Günther 1876).



Pseudophilatus wayanadensis — *Raorchestes anili*

Raorchestes akroparallagii — *Raorchestes glandulosus*

Raorchestes ponmudi — *Raorchestes nerostagona*

Racophorus malabaricus — *Racophorus laterralis*

Polypedates pseudocruciger — *Uperdon triangularis*

Fig. 3 **S**ome of the frog species found in shade coffee plantations **in** Wayand, Kerala, India. *Photographs credits* Dr. Anil Sachariya

Know the Nexus of Carbon Stock of Coffee Production System and Biodiversity

Wayanad and **the** adjoining coffee grown areas experience a shift towards mono crop and high input farming. There are wide spread deliberate attempts for growing coffee completely exposed to sun with high input agro-chemicals for getting the maximum crop productivity, and income. This change in farm practices and intensified use of farm inputs becomes a big sustainability issue, particularly in the context of biodiversity loss and the consequent climate vulnerabilities. The region is also experiencing unprecedented and irreversible climate variations like weakening in the early phase of the south-west monsoon precipitation, increasing polarisation of daily rainfall, more frequent heavy rainfall days and rising minimum temperature. The challenges associated with climate variations result in staggering poverty, especially amongst the resource poor tribe communities like *Paniya, Adiya* and *Kattunaikka* in Wayanad. It is also a fact that the indirect benefit that enjoyed by people of the region in the form of increased removal of carbon through integrated coffee cultivation also has now getting diminished.

In the light of climate change mitigation, carbon (C) storage in both living biomass and in the soil is a key ecosystem service provided by forests and agroforests (Bonan 2008; Miles and Kapos 2008; Beenhouwer et al. 2016). In particular, the ecosystem services of traditionally maintained, shaded Arabica and Robusta coffee farms become very prominent largely for increasing carbon removal. The most important function of the shade grown traditional coffee **agroforestry** system is the reduction of **the** concentration of Carbon in the atmosphere. It is estimated that one hectare shade**-**grown coffee farm with large forest trees can sequester 70–80 tonnes of carbon per hectare, which is more or less equivalent to the carbon stored in **an** equal area of forest. A fully sun–grown or open coffee in one hectare can only store less than 10 tonnes of carbon (Noponen et al. 2012). A study in the adjacent Coorg region reported the soil organic carbon sequestration potential of **the** shaded coffee system averaged 3.43 t/ha and microbial organic carbon content 831.76 mg/g compared to 1.84 t/ha and 669.46 mg/g respectively that of **the** partially shaded system with exotic silver oak trees (Kumar 2017). One of the major challenges at the interface of climate change and ecosystem science is to identify points of convergence between C storage and biodiversity conservation (Phelps et al. 2012). In general, a higher C storage potential is assumed to co-occur with biodiversity conservation (Venter 2014; Beenhouwer et al. 2016). Two recent studies found a correlation when soil C storage was included. Woody plant species richness was associated with higher total C (aboveground and soil) storage in a recent study of Costa Rican coffee agroforestry systems by Hager (2012) and Saha et al. (2009) found a positive correlation between soil organic C and plant diversity in home gardens of India (Richards and Mendez 2013).

Table 2 Earthworm diversity recorded from shade coffee farms

Family	Name
Glossoscolecidae	• *Pontoscolex corethrurus*
Almidae	• *Glyphidr ilus annandalei*
	• *Glyphidrilus achencoili*
Megascole cidae	• *Megascolex konkanensis*
	• *Megascolex trarancorensis*
Oniligastridae	• *Drawida pellucida*
	• *Drawida travancorensis*
	• *Drawida g hatensis*
Eudrilidae	• *Eudrilus eugeniae*

Table 3 Termites diversity recorded from coffee farms

Sub family	Name
Macrotermitinae	• *Odontotermes anamallensis*
	• *Odontotermes yadevi*
	• *Microtermes unicolor*
Apicotermitinae	• *Speculitermes chadaensis*
Nasutitermitinae	• *Nasutitermes matangensis*
	• *Grallatotermes niger*
Termitinae	• *Dicuspiditermes incola*
	• *Pseudocapritermes nr fletcheri*

Table 4 Ants diversity in the coffee farms

Sub family	Name
Formicinae	• *Polyrhachis rastellata*
	• *Oecophylla smaragdina*
Myrmecinae	• *Tetramorium smithi*
	• *Solenopsis geminata*
	• *Myrmycaria brunnea*
	• *Paratrechina longicornis*
Ponerinae	• *Diacamma indicum*
	• *Odontomachus haematoges*
	• *Leptogenys minchinii*
	• *Bothroponera rufipes*
Pseudomyrmecinae	• *Tetraponera rufonigra*
Dolichoderinae	• *Tapinoma melanocephalum*
	• *Tapinoma sessile*

Table 5 Traditional pepper varieties cultivated in Wayanad, Kerala, India

Sl. No	Local Name	Description
1.	Aimpiriyan	High yielding, Performance excellent in higher elevations, good in quality, less weight, easy to harvest
2.	Arkalamunda	Moderate and regular bearer, medium in quality, easy to harvest
3.	Balankotta	Cultivar with large droopy leaves, moderate and irregular bearer medium in quality
4.	Chengannurkodi	Moderate yielder, medium in quality
5.	Cheryakanikadan	Popular in north Kerala, moderate and early bearing variety
6.	Jeerakamundy	Cultivar with small leaves, and short spikes
7.	Kalluvally	Promising North Kerala cultivar, good yielder, medium in quality with high dry recovery, drought tolerant
8.	Karimunda	Most popular cultivar suitable most of the black pepper growing areas, high yielder and medium in quality
9.	Kottanadan	High yielding cultivar, medium in quality, drought tolerant variety
10.	Kuthiravally	A cultivar with long spikes, high yield and good quality
11.	Narayakodi	Moderate yielder with medium quality
12.	Neelamundi	Good yielder, medium quality, tolerant to phytophthora infection
13.	Nedumchola	A cultivar with small leaves and short spikes, moderate yielder
15.	Valiyakaniyakadan	A cultivar with larger leaves, medium in yield and quality
16.	Vellanamban	Relatively moderate yielder and medium in qualitycharecterised by the white colour to the young shoot tip
17.	Chumalakody	Medium ovate leaves, short spikes, medium yield and quality
18.	Karimkotta	Large leaves, short spikes, regular bearer and good yielder
19.	Cherukodi	Narrow leaves, dark green, short spikes, bearing in alternate years, high quality
20.	Uthirankotta	Predominantly female, disease resistant, High weight, poor yielder
21.	Kariyilamundi	Short spikes, small fruits, poor yielder
22.	Wayanadan	Large leaves and fruits, high yielder and good quality, alternate bearer
23.	Karimundi	More spikes, more weight, small berry
24.	Arakkalamundi	Suitable to hilly areas
25.	Muttiyarmundi	Moderate yield

Promoting Coffee Value Chain as a Carbon Neutral Brand

India exports almost eighty percent of the coffee produced in the country and supplies about 5% of the total coffee production **in** the world. Italy (mostly the Robusta coffee) and Russia (both Robusta and Arabica) are the top two buyers of Indian coffee, followed by Belgium, Spain, Finland, Germany, Netherlands, France, Japan and

USA. "Monsooned Malabar Arabica Coffee "is a **specialty** coffee of India, sourced from shade coffee plantation and has GI protection. This coffee is produced from the harvested cherries that are exposed to **rain** and winds of **the** monsoon for about 3–4 months to make the **pH** balance of the seeds neutral. But, this practice has been almost disappeared or restricted to only with some elite planters. There is a huge potential to create **an** impact on farmers' income by making shade coffee farming a profitable venture and free from climate change risks (Kumar 2017). Because agro forests are human-managed systems, this may present an opportunity for farmers to manage such systems for greater C sequestration. However, this would require a re-examination of mechanisms to support or reward shade coffee farmers (Davis and Mendez 2011; Richards and Mendez 2013). For example, small-scale farmers have generally been excluded from REDD, Clean Development Mechanism (CDM), and other PES schemes for C sequestration because of the expense involved in managing multiple small farms and the lower per-hectare mitigation benefits relative to afforestation and reforestation projects (Wunder and Borner 2012; Richards and Mendez 2013). Therefore, the promotion of shade grown, biodiversity-rich and climate resilient Coffee can emerge as a **highly valued** commodity in **the** world coffee market. Revival of the shade grown coffee system amongst the small growers with appropriate steps in marketing the coffee as a speciality product (carbon neutral and grown in bio-diverse environment) can improve the farm income and enhance the coffee agro-ecosystem services.

Conclusion

Agroforestry systems have been recognized for their potential to sequester large amounts of C (Noponen et al. 2013). Agro ecosystems have the potential to act as carbon sinks and carbon storage pools while contributing to increased farm production, environmental conservation and poverty alleviation (Pandey 2002; Manjunatha et al. 2016). On the other hand, agroforestry systems have substantial potential to conserve native biodiversity and provide ecosystem services. In particular, agroforestry systems have the potential to conserve native tree diversity and sequester carbon for climate change mitigation (Richards and Mendez 2013). Coffee farms as agroforestry may contribute to GHG mitigation and biodiversity conservation in a synergistic manner which has implications for the effective allocation of resources for conservation and climate change mitigation strategies in the agricultural sector (Hager 2012). It is possible to produce high quality coffee without destructing biodiversity or contributing negatively to some of the critical ecosystem services. One of the important steps to make the shade Coffee Agro-forestry System globally visible is **a** creation of scientifically valid evidences on the biodiversity and ecosystem services, and the emission- mitigation potential of this system. Evidence from such study will also help to promote eco-tourism in the coffee production areas. There are no serious studies in India that analyzed the carbon emission in the entire value chain of Indian Coffee production, processing, transporting and consumption system. The need for **a** trans-disciplinary approach inclusive of the private industries in understanding the entire life cycle of the coffee production system is urgent for developing coffee production system and the value chain as a carbon neutral brand. Also, there is a need to work upon "consumption awareness" which can positively impact on sustainable production of coffee. Since management practices such as shade use and reforestation influence both climate vulnerability and carbon stocks in coffee, there may be synergies between climate change adaptation and mitigation that could make it advantageous to jointly pursue both objectives (Rahn et al. 2013). Importantly, there is **a** need for policy incentives that encourage the planting and maintenance of shade trees in coffee plantations for the benefit of carbon sequestration (Tumwebaze and Byakagaba 2016). Accordingly, biodiversity of agro-ecosystems **have** important consequences for long-term carbon storage, and thus warrants incorporation into the design, implementation, and regulatory framework of mitigation initiatives (Diaz et al. 2009). There have been significant efforts to develop robust methods to account for the benefits, if any, of sequestration and temporary storage and release of biogenic carbon. However, there is still no overall consensus on the most appropriate ways of considering and quantifying it (Brandão et al. 2013). Thus, this paper emphasizes that the sustainably grown coffee helps to increase climate resilience, contributes to carbon mitigation, conserves biodiversity and stabilizes ecosystems while also helping farmers stabilize and improve their income and livelihood (Stifung 2017).

Limitations

Although this paper was thoughtfully prepared and reached its aim, there were some limitations. Some of the limitations of the paper includes that (1) this paper has only outlined the conceptual nexus of coffee, climate and biodiversity, however, more investigations are warranted to establish the strong scientific approach to make connections among the three; (2) this paper has made an attempt to deepen the understanding on carbon stocks of the shade coffee production system of India, nonetheless a strategic methodological approach **is** required to assess the carbon stocks of the shade coffee production system of India; (3) lack of availability of carbon stock information at the local level of the shade coffee farms in India is one of the important limitations of this paper to present any quantifiable information of the carbon stocks of the shade coffee production system.

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Implications for Biodiversity of Potentially Committed Global Climate Change (from Science and Policy)

Peter D. Carter

Abstract Climate change impacts on biodiversity that are observed today are substantially less than those predictable in the future. Vital policy-relevant information regarding global climate change and biodiversity includes the sources of increased future global warming commitment, which stem from both climate change policy and climate science. Full, long-term (over many 100s of years) equilibrium global warming commitment, calculated by the constant atmospheric greenhouse gas composition, is put at 'about 2 °C' by the IPCC 2014 assessment. Significant further committed warming at 2 °C is expected due to weakened terrestrial carbon sinks and large planetary sources of carbon feedback emissions. Committed climate change due to policy is calculated from national emissions targets. Together these policy targets lead to over 3 °C global warming by 2100, which will increase much more after 2100. Commitment clearly shows the climate, oceans and biodiversity global emergency, requiring the immediate decline of emissions with supporting responses that are well known and universally recommended.

Introduction

Climate change will exacerbate the ongoing impacts of biodiversity loss. How much depends on already committed (locked in) global warming, and that depends on both climate science and policy commitments on emissions.

This paper grew out of my interest in exploring the most policy-relevant aspects of climate change, in particular regarding future life. Predicting the higher degrees of future climate change the world faces is essential for driving conservation and for planning mitigation and adaptation. The greatly increased loss of biodiversity in the future due to future global climate change is assessed here by looking at today's already committed degrees of global climate change. This chapter treats biodiversity loss and ecosystem loss as one and the same. Climate change increases biodiversity

P. D. Carter (✉)
Climate Emergency Institute, 4708 Captains Crescent, Pender Island, BC V0N 2M2, Canada
e-mail: climatemergencyinstitute@gmail.com

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loss, and biodiversity/ecosystem loss increases climate change by reducing land carbon sinks, e.g., forests.

That the world is in a very large extinction event has been known for many years. The same applies to climate change, as recorded in the assessments of the Intergovernmental Panel on Climate Change (IPCC) from 1990 to 2014. It was in 1996 that Richard Leakey published *The Sixth Extinction: Patterns of Life and the Future of Humankind* (Leakey and Lewin 1996). In 2017, Ceballos, Ehrlich, and Dirzo were published under the shocking title *Biological annihilation* via *the ongoing sixth mass extinction signaled by vertebrate population losses and declines*. What is less well known is that already committed global climate change will make the extinction rate far worse than projected (Urban 2015).

Increasing Climate Change Increases Biodiversity Loss

In its 2007 fourth assessment, the IPCC said:

> In the medium term (i.e., decades), climate change will increasingly exacerbate human-induced pressures, causing a progressive decline in biodiversity. Projected future climate change and other human-induced pressures are virtually certain to be unprecedented compared with the past several hundred millennia. (IPCC 2007, Working Group II 4.1.2.)

Climate change impacts further increasing today's accelerating biodiversity loss (Ceballos et al. 2015) would be a truly catastrophic case of abrupt climate change, as explained by the National Research Council (NRC) (2013): 'The abrupt changes that are already underway […] include increases in extinction rates of marine and terrestrial species.' The NRC states that unchecked habitat destruction, fragmentation, and over-exploitation combined with the ongoing pressures of climate change could result in a mass extinction equivalent in magnitude to the one that wiped out the dinosaurs, and that it conceivably could occur before the year 2100. The predicted 'velocity' of climate change—that is, how fast populations of a species would have to shift in order to keep pace with the local climate envelope shift—is unprecedented.

Future Catastrophic Biodiversity Decline

All sources project large increases in species extinctions from global climate change. Even the best-case emissions scenario with immediate global emissions decline increases the risk of extinctions (IPCC 2014a, WGII Summary for Policy Makers). Both global climate change due to greenhouse gas (GHG) emissions and the increased extinction of species by climate change have great inertia, each taking decades (or more for extinction). In view of the fact that the world is in or is entering a catastrophic sixth major extinction event already, the effect of global climate change would appear to be potentially cataclysmic to biodiversity, which is addressed in this chapter.

The challenge of preserving enough habitat for biodiversity to recover in the future is enormous. Pimm et al. (2014) (in arguably the most comprehensive research paper on future biodiversity loss under global climate change) say that conservation is key, backed up by the point that the rate at which mammals, birds, and amphibians have slid toward extinction over the past four decades would have been 20% higher were it not for conservation efforts. Although the paper says that data and research lag far behind what is needed, we nevertheless do know the two big solutions that would have enormous benefit. These are: (1) conservation through the termination of deforestation, and (2) termination of industrial age fossil fuel emissions. The success of conservation is a strong argument for the huge conservation upgrade in the proposed plan of Wilson (2016) to protect half of the Earth's land and oceans, and to end deforestation.

Several Sources of Committed Climate Change and Biodiversity Loss

Committed climate change and biodiversity loss stem from both climate change policy and climate system science. If policies are improved, the policy commitment might lessen. Climate system commitment is actually much more than is published and is irreversible (locked in). Commitment further reinforces a cataclysmic outcome for global biodiversity.

The data on commitment paints a terrible picture for the future of biodiversity and the natural world, so at the outset let us be reminded that we have all the solutions. They are well known, as explained by Sutter (2016) in 'How to stop the sixth mass extinction', which included E. O. Wilson's Half-Earth Project. These solutions are developed, and they can be readily applied.

Biodiversity loss is already extreme and accelerating. According to the NRC (2013), the extreme rate of acceleration in biodiversity loss is probably unprecedented in 65 million years; today's sixth mass extinction event reveals current biodiversity loss as an abrupt planetary catastrophe that will be further greatly accelerated by a committed, unavoidable increase in global climate change. Data sets (see stateofourclimate.com) show that all climate change indicators from 1900 are accelerating, particularly atmospheric CO_2, global surface warming, and amplified Arctic warming, as well as ocean heating, ocean acidification, and ocean deoxygenation.

In terms of policy, this is an Earth (or biodiversity) emergency requiring immediate measures for concerted and energetic mitigation, adaptation and conservation. Assessing the projected committed impacts on ecosystems and biodiversity in global climate change models is essential for urgently planning both biodiversity conservation measures and climate change mitigation measures, and to plan strategies for adaptation. Furthermore, committed climate change impacts on biodiversity must be projected far beyond 2100 (the horizon used by the IPCC).

In doing such an assessment, it is necessary to address the several sources that cause greater committed future global climate change. In general, there are two types of climate change commitment: (1) locked-in commitment due to climate change science (for example, due to climate system inertia, observed ecosystem damage and loss at the time observed will be practically irreversible); and (2) climate change emissions policy commitment. Both lead to a far greater degree of global climate change than today's—which is already having severe disastrous to catastrophic local and regional impacts on all continents.

Commitment Due to Emissions Policies

Policy commitment—current government policy—is recorded by the national government emissions targets filed with the United Nations as intended nationally determined contributions (INDCs). Combined, these will lead to a substantial increase in global emissions by 2030, according to an update from the UN Climate Change Secretariat (2016). Indeed, these emissions targets lead to a global warming of over 3 °C by 2100 (which will be much higher after 2100), according to Climate Action Tracker (2017). This warming by 2100 is triple today's warming of just over 1 °C. Because of ocean thermal inertia, full equilibrium warming long after 2100 would be 6 °C.

Also on policy commitment, the 1992 Framework Convention on Climate Change (UN Climate Change Secretariat 1992), to which all governments are bound, requires the stabilization of greenhouse gas concentrations in the atmosphere at a level sufficient to allow ecosystems to adapt naturally to climate change. Stabilization of atmospheric GHG concentrations is the right metric to use because, unlike the global average surface warming alone, the atmospheric GHG concentrations account for additional committed warming in the future. However, atmospheric GHG concentrations are already far above a safe level for ecosystems, on land and in oceans, and CO_2 increase is accelerating.

Climate System Science Commitment

The climate system inertia of the ocean heat lag commits warming by 2100 to double long after 2100, which can be seen in Fig. 1 by 2300, and which is best explained by the NRC Climate Stabilization Targets (2011). Added to that, there will be extra warming from carbon feedback emissions. A significant degree of global warming causes more emissions and then more warming, so at least a doubling of warming from now on is predictable. Based on a 2012 global warming of 0.85 °C, the IPCC fifth assessment's WGI (2013) estimated that the climate system inertia commitment

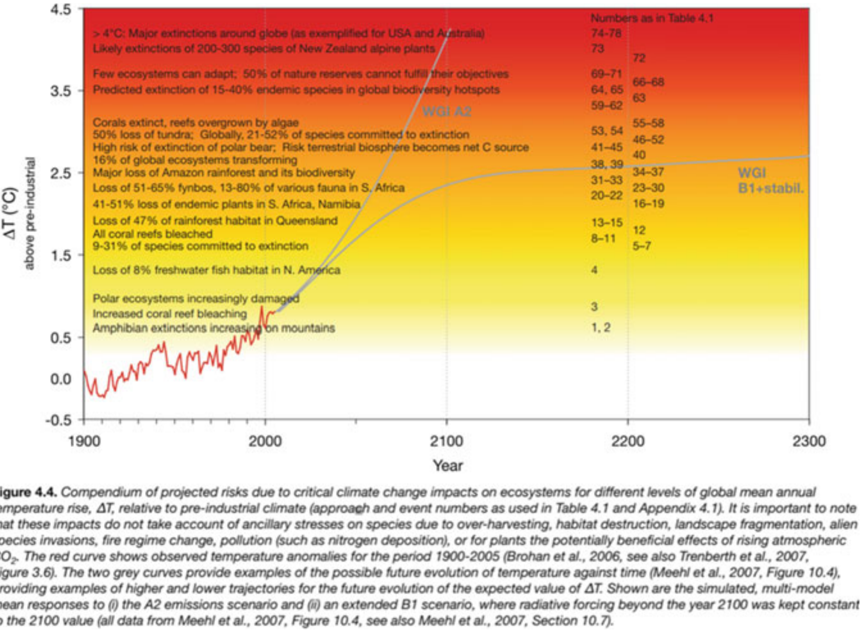

Fig. 1 Projected climate change impacts on ecosystems and species according to degrees of global warming (vs. pre-industrial) (Image reprinted courtesy of IPCC Climate Change 2007 Working Group II Fig. 4.4, published by Cambridge University Press)

due to the ocean heat lag would be an extra 0.6 °C by 2100 and a full equilibrium warming commitment of 'about 2 °C' long after 2100 (WGI, Chap. 12). This does not account for extra warming by carbon feedbacks. Global warming in early 2018 was 1.1 °C and atmospheric CO_2 was 408 ppm (March 2018 seasonally adjusted mean CO_2), which would put today's committed warming at about 2.08 °C. Atmospheric CO_2 is increasing faster than ever. This can only be expected to lead to a collapse of global and regional ecosystem biodiversity. Also, both committed global temperature increases (i.e., policy and science) last for a thousand or more years (Solomon et al. 2009), over which time many more species will be driven to extinction.

Climate Change Danger Limits

The first estimate for a climate change danger limit was in 1990 and was based on safety for ecosystems. 'A maximum sea level rise of between 0.2 and 0.5 m above the 1990 global sea level' and 'a maximum rate of rise of between 20 and 50 mm per decade' were recommended to 'permit the vast majority of vulnerable ecosystems, such as natural wetlands and coral reefs, to adapt' because 'beyond this rate of rise, damage to ecosystems will rise rapidly' (Rijsberman and Swart 1990). A mean global temperature rise limited to a maximum rate of change in temperature of 0.1 °C per decade was recommended based on an understanding of the vulnerability of ecosystems.

While global temperature increase in 2016 was just above 1.0 °C, scientists in 1990 believed that 'temperature increases beyond 1 °C may elicit rapid, unpredictable, and non-linear responses that could lead to extensive ecosystem damage' (Rijsberman and Swart 1990). Since the 2012 UN Paris Climate Agreement, the science has treated 1.5 °C, rather than 2 °C, as the danger limit.

Rijsberman and Swart (1990) also recommended a maximum CO_2-equivalent concentration of 330–400 ppm in the atmosphere. Yet, atmospheric CO_2-equivalent in 2016 was 489 ppm (NOAA 2017), far above ecosystem safety.

Although not so defined in the Paris Agreement, since 2009 the standing equilibrium-warming target has been reduced to a target only by 2100. Climate system commitment means that this will be double long after 2100.

Climate Change and Biodiversity Trends

The IPCC assessments, the main source of data and information for this chapter, let us know how much and how long we have known about the global climate change impacts to biodiversity. With each succeeding assessment since 1990, the climate change situation for biodiversity has been found, with more research, to be worse, not better. Furthermore, the uncertainties make the predictable impacts on biodiversity considerably worse than published.

Loss of population abundance is a major indicator of biodiversity decline. The committed species extinction rate at increasing degrees of climate change was used in the IPCC's fourth assessment (2007). The last World Wide Fund for Nature Living Planet Report (2016) on species population abundance shows a sustained rapid decline since 1970. Global biodiversity is declining at an alarming rate. The 2016 WWF's Living Planet Index reveals that global populations of fish, birds, mammals, amphibians and reptiles declined by 58% between 1970 and 2012. We could witness a two-thirds decline in the half-century from 1970 to 2020—unless we act now to reform our food and energy systems.

In this time of continuing global warming, ecosystems matter a lot to global, as well as regional, biodiversity and the future survival of most of the world's species. Some ecosystems hold enormous sources of potential carbon feedback emissions that are vulnerable to release by global warming acting upon these ecosystems (IPCC 1990). These large vulnerable carbon pools include permafrost, high latitude peatlands, tropical peatlands and forests subject to fire and/or dieback.

The Worst-Case Scenarios

The IPCC (2014a) projected a global warming by 2100 of up to 7.8 °C when including climate uncertainty. The worst possible effect of global surface warming on all of life is an ecosystem change effect of the Arctic releasing wetland and permafrost carbon. Because global warming will last for over 1000 years (Solomon et al. 2009), we can expect carbon feedback emissions from the several enormous planetary pools of carbon. The risk of planetary catastrophic 'runaway carbon dynamic' was first recognized by the IPCC in the third assessment (2001, 19.6.3.2. Large-Scale Singularities). Global energy-related CO_2 emissions rose by 1.4% in 2017, for a historic high of 32.5 Gt. (International Energy Agency 2018). Global emissions and atmospheric concentrations are tracking closest to the IPCC worst-case scenario (Saunois 2016).

Climate Change and Biodiversity Loss Interaction

Another great concern is the potential amplifying negative interaction between biodiversity loss and global climate change, where each makes the other worse in a negative synergistic manner for both. Climate change reduces the land carbon sink through its impacts on forests, leaving more CO_2 in the atmosphere. Brook et al. (2008) point out that species loss can occur directly and abruptly if habitat destruction or overexploitation of populations is severe. 'Yet the final descent to extinction is often driven by synergistic processes (amplifying feedbacks) that can be disconnected from the original cause of decline.' They reviewed:

> recent observational, experimental and meta-analytic work which together shows that owing to interacting and self-reinforcing processes, estimates of extinction risk for most species are more severe than previously recognized. As such, conservation actions which only target single-threat drivers risk being inadequate because of the cascading effects caused by unmanaged synergies. (Brook et al. 2008)

Their paper anticipated that climate change would interact with and accelerate ongoing threats to biodiversity, such as habitat degradation, overexploitation and invasive species.

This synergistic interaction, taken further by Segan et al. (2016), has to be accounted for in a general and region-specific manner to plan priorities in conservation, mitigation and adaptation. Adaptation is urgent today but cannot be expected to be successful for long without concomitant mitigation; a long-held global climate change principle is that adaptation must be accompanied by mitigation.

The IPCC fourth assessment (2007) said that global extinction is a crucial key issue 'because of a very likely link between biodiversity and ecosystem functioning in the maintenance of ecosystem services.' Grace et al. (2016) found that communities rich in species are substantially healthier and more productive than those depleted of species. Here we take the health of ecosystems and biodiversity as one entity called 'ecosystem biodiversity.'

As it is, the current accelerating rate of species extinction is 1000 times the background rate (Pimm et al. 2014). With committed and feedback-accelerated climate change, this is likely to become the highest rate of any extinction event on Earth, with accelerating losses for every degree rise in global temperatures (Urban 2015). Today's emissions targets, which substantially increase (rather than decrease) global emissions by 2030, are bound to make this extinction qualify as the fastest ever. This policy commitment is, to a large extent, avoidable and would be greatly reduced if governments followed the recommendations of the climate and ocean change scientists, which is to immediately and rapidly reduce global emissions.

What the IPCC Assessments Say

Based on a 2012 global warming of 0.85 °C, the IPCC's fifth assessment (2013) estimated a full-equilibrium warming commitment, due to climate system inertia, of 'about 2 °C' long after 2100. Remember, global warming has already reached just over 1 °C since industrialization.

The IPCC's third assessment WGII (2001) Summary for Policy Makers (SPM)—which is approved by all world governments—reported emergent findings that regional changes in climate, particularly increases in temperature, had already affected a diverse set of physical and biological systems in many parts of the world, with associations between changes in regional temperatures and observed changes in physical and biological systems documented in many aquatic, terrestrial, and marine environments.

The IPCC fourth assessment's WGII (2007) SPM reported with high confidence that recent warming was strongly affecting terrestrial biological systems and changes in freshwater and marine biological systems, with declining oxygen levels and circulation. Approximately 20–30% of plant and animal species assessed were found to be at additional increased risk of extinction above 1.5–2.5 °C. For increases in global average temperature exceeding 1.5–2.5 °C and in concomitant atmospheric carbon dioxide concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions, and species' geographical ranges, with predominantly negative consequences for biodiversity.

The IPCC fourth assessment provided a graph (see Fig. 1) of more specific ecosystem and species impacts (IPCC 2007, WGII Fig. 4.4). Line B1 is the temperature increase at constant atmospheric concentrations from 2100 up to committed warming by 2300. Degrees of warming would be treated as committed for policy relevance. These impact on top of ongoing global ecosystem degradations.

For an in-depth projection of ecosystem impacts, see the IPCC fourth assessment's (2007) WGII Table 4.1. Their extinction projections relied largely on Thomas et al. (2004), a paper that remains very important, as it is rich with information on global climate change and biodiversity. The topic has been revisited and the Thomas projections in general confirmed. The Thomas et al. projections include a high-emissions climate change scenario, the latter being the closest to that which the world is now tracking. The paper draws several crucial conclusions:

> Minimum expected (that is, inevitable) climate-change scenarios for 2050 produce fewer projected 'committed extinctions' by about half of those predicted under maximum expected climate change. These scenarios would diverge even more by 2100. Returning to near pre-industrial global temperatures as quickly as possible could prevent much of the projected, but slower acting, climate-related extinction from being realized. (Thomas et al. 2004)

This is a call for the immediate global decline of emissions, as in the IPCC fifth assessment (2014a) WGIII best-case scenario.

A big point of the Thomas et al. (2004) paper was that by 2050, global climate change could take over from direct habitat change as the main cause of special extinctions and biodiversity loss. The worst case was a committed 58% of all species by 2050 by climate change alone. The paper estimated that an additional 34% of all original species would be committed to extinction due to habitat destruction from 2000 to 2050. The paper adds that extinction risks might be even higher taking other factors into account.

One of the worst possible outcomes for biodiversity is synergy between global climate change and the other non-climate change impacts, where the combined effects of multiple stressors are greater than the sum of individual effects. Assessments have assumed that multiple stressors lead to cumulative linear effects, with little interaction among threats considered. Findings serve as a reminder that these assessments should seriously consider the potential synergy of multiple threats interacting; Fortini and Dye (2017) indicate the seriousness of 'potential synergisms and compounding threat interactions, especially with stressors that are as complex as climate change.'

It is important to realize that because of commitment, to prevent an impact projected to occur at, for example, 3 °C, global warming must be limited to 1.5 °C due to total climate system inertia.

The IPCC's (2014a) fifth assessment is grim for the future of biodiversity and species:

> A large fraction of both terrestrial and freshwater species faces increased extinction risk under projected climate change during and beyond the 21st century, especially as climate change interacts with other stressors, such as habitat modification, over-exploitation, pollution, and invasive species (*high confidence*). (IPCC 2014a)

Extinction risk is increased under all IPCC (2014a) RCP (representative carbon pathway) scenarios, with risk increasing with both magnitude and rate of climate change. The IPCC (2014b) graphic below (Fig. 2) shows projected impacts on biodiversity. Warming and impacts are only up to 2100. As shown in Fig. 2, the assessment said that many species will be unable to track suitable climates under all scenarios except the best case (RCP2.6) this century. Those that cannot adapt sufficiently fast will decrease in abundance or go extinct in some or all of their ranges, with large losses of biodiversity.

The IPCC (2014a) assessment shows the velocity capacity of species compared to the rate of climate change. It shows that above the RCP2.6 best-case emissions

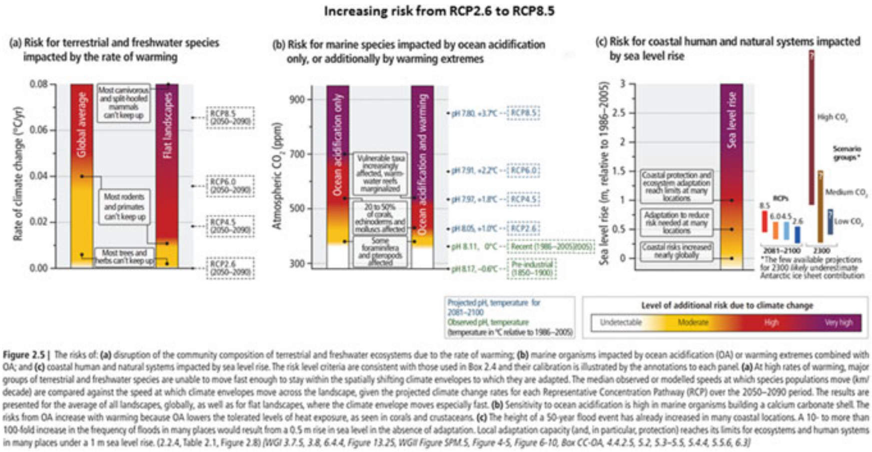

Fig. 2 Projected impacts on ecosystems and species (Image reprinted courtesy of IPCC Climate Change 2014 Synthesis Report Fig. 2.5, published online by IPCC, Geneva, Switzerland)

scenario, which causes the slowest rate of climate change, most trees and herbaceous plants cannot keep up with climate change, leading to an extremely high risk of terrestrial extinctions in general. As the best-case emissions scenario, RCP2.6 is the only scenario not above 2 °C by 2100; it is an increase of 1.6 °C from pre-industrial.

According to the IPCC's fifth assessment (2014b) Synthesis Report, continued emission of greenhouse gases increases 'the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.' Furthermore, 'many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. […] The risks of abrupt or irreversible changes increase as the magnitude of the warming increases.'

The IPCC (2014a) assessment predicted that within this century, magnitudes and rates of climate change associated with all but the best-case emissions scenario (immediate global decline) pose high risk of abrupt and irreversible impacts on terrestrial and freshwater ecosystems, including wetlands. These impacts include the potential of ecosystems to become a source of feedback carbon emissions. Examples that could lead to such substantial impacts on climate are the boreal-tundra Arctic system and the Amazon forest. Carbon stored in the terrestrial biosphere (e.g., in peatlands, permafrost, and forests) is susceptible to loss to the atmosphere. Increased tree mortality and associated forest dieback are projected to occur in many regions this century, due to increased temperatures and drought. Feedback from forest dieback poses risks to carbon storage and biodiversity. Indeed, forest dieback has already started, with the IPCC (2014a) reporting that 'extensive tree mortality and widespread forest dieback linked to drought and temperature stress have been documented on all vegetated continents.' This includes the great Amazon and Boreal forests.

> The forests of the Amazon Basin are being altered through severe droughts, land use (deforestation, logging), and increased frequencies of forest fire. Some of these processes are self-reinforcing through positive feedbacks, and create the potential for a large-scale tipping point. […] Climate change contributes to this tipping point by increasing drought severity, reducing rainfall, and raising air temperatures. (IPCC 2014a, Fig. 4.8)

In 2017, the first-ever global database of trees (by Beech et al. 2017) revealed that out of 60,065 total, 9600 tree species are threatened with extinction. Adding that threat to so much actual tree mortality and forest dieback makes the impact on biodiversity in general very clear. [The IPCC (2014a) assessment of species extinctions goes only up to 2100, which does not constitute total committed extinctions since warming is committed to substantially increase after 2100.]

The fact that trees and herbaceous plants are unable to keep up with the rate of climate change equivalent to a global warming of 1.6 °C by 2100 is of enormous concern because of a domino effect: a plant extinction impacts many animals. Cascading biodiversity loss as a result of climate change originates mostly from plant species and is indirectly transferred to animal species. Therefore, climate change has an even greater negative effect on the biodiversity of animals through losses of plants and trees (Schleuning et al. 2016). Kew's (2016) State of the World's Plants 2016 estimated that 1 in 5 plants are threatened with extinction.

Coastal biodiversity is high. But according to the IPCC fifth assessment (2014a), coastal biodiversity is threatened by sea level rise and eutrophication-driven deoxygenation. Figure 2 shows that impacts have started.

Ocean biodiversity is severely threatened by the combination of deep open ocean heating, deoxygenation and acidification. These are all accelerating—with ocean heating going deeper—and the IPCC (2014a) says that they are predicted to combine synergistically, creating a situation with the potential for ocean biodiversity collapse, which alone would be a calamity for life on land.

Marine species are being impacted by ocean acidification and warming extremes (IPCC 2014a). The progressive acidification of oceans due to increasing atmospheric carbon dioxide is expected to have negative impacts on marine shell-forming organisms (e.g., corals) and their dependent species. As Fig. 2 shows, already some foraminifera and pteropods are being affected. At an acidification with a global surface warming of 1.6 °C, 20–50% of corals, echinoderms and mollusks are affected. At a global warming of 2.4 °C, vulnerable taxa are increasingly affected and warm water coral reefs are marginalized.

There is little to no effective adaptation available for ocean ecosystems and species (IPCC 2014a, SPM Box 2 Table 1). For all emissions scenarios except the best-case immediate global emissions reduction scenario, ocean acidification poses substantial risks to marine ecosystems, associated with impacts on the physiology, behaviour, and population dynamics of individual species from phytoplankton to animals:

> Ocean acidification acts together with other global changes (e.g., warming, decreasing oxygen levels) and with local changes (e.g., pollution, eutrophication). Simultaneous drivers, such as warming and ocean acidification, can lead to interactive, complex, and amplified impacts for species and ecosystems. (IPCC 2014a, WGII SPM)

Coral reefs worldwide would seem committed to extinction at a 2 °C global warming plus acidification. To protect at least 50% of the coral reef cells, global mean temperature change would have to be limited to 1.2 °C (1.1–1.4 °C), not taking ocean acidification effects into account (Frieler et al. 2013).

From 1910 to 2010, there is a recorded 70% decline in ocean biomass and fish stocks (IPCC 2014a). The progressive expansion of oxygen minimum zones and anoxic 'dead zones' is projected to further constrain fish habitat. Open-ocean net primary production is projected to redistribute and to fall this century globally under all RCP scenarios. Climate change adds to the threats of over-fishing and other non-climatic stressors (IPCC 2014a).

Finally, new research shows that the phenomenon of interspecies mismatching/mistiming, another huge climate change concern, is now happening (Kharouba et al. 2018), adding a further devastating layer to climate change impacts on biodiversity.

Limitations of the Chapter

The climate change projections applied in this paper are medians that do not account for higher climate sensitivities at higher warming, nor extra emissions from large sources of carbon feedback emissions. Uncertainties including abrupt changes and tipping points are not applied in IPCC warming projections. Interactions of multiple adverse climate change impacts on species and interspecies interactions are not quantified. The IPCC (2014a) mentions that ancillary stresses on species due to overharvesting, habitat destruction, landscape fragmentation, alien species invasions, and fire regime change are not accounted for in projections on species. It also notes under uncertainties that capacity for, and limits to, ecological adaptive processes are known only in a few cases and tipping points remain a major source of uncertainty with high potential consequences.

For a standard environmental health risk assessment, the approach could be further developed with current near worst-case emissions scenarios and worst-case ranges of projections.

Conclusions and Recommendations

Due to climate system inertia, the world is in a committed biodiversity loss emergency affecting both land and oceans. The global aggregate of national emissions policies commits (indeed, condemns) the world to a future global biodiversity collapse. The now recommended global warming limit of 1.5 °C, on top of the 6th mass extinction, is still deadly for global biodiversity. It is important to keep in mind that in the IPCC (2014a) projections, climate system commitment is 2 °C equilibrium warming and policy commitment is over 3 °C by 2100, which is a full policy equilibrium commitment of over 6 °C after 2100.

The imperative now is mitigating catastrophic global climate change impacts to ecosystems and biodiversity. From multiple lines of evidence, we see that this requires the immediate and rapid decline of global greenhouse gas emissions, reaching near zero within decades. This depends on achieving some form of safe removal and sequestration of some atmospheric CO_2, which, for the sake of biodiversity, definitely cannot be biomass energy (burning) with carbon capture and sequestration (BECCS).

The imperative of near-zero emissions by mid-century requires ending fossil fuel subsidies fast; ending deforestation and deforestation-driving government subsidies; and charging central fossil fuel producers the full environmental and social costs of their pollution.

Clearly, the imperative is also for a massive global upgrade of conservation (protecting huge swathes of the world's land and oceans, as suggested in the proposed plan of E. O. Wilson in 2016 to protect half of the Earth's land and oceans) and attempts at assisted ecosystem adaptation, with priority on global biodiversity hotspots. This will require massive injections of funding for the necessary research, conservation, and adaptation.

The effective measures for ecosystem adaptations are essentially the same as for mitigation, that is, large expansion of protected areas and termination of deforestation. The strategies of coastal afforestation, watershed management, and maintaining wetlands and urban green space (IPCC 2014a, Table SPM.1) will only be successful if they accompany the most aggressive global climate change mitigation measures possible.

Mitigation of both climate change and biodiversity loss is, in theory, achievable, with large countervailing benefits to human populations and the future of humanity. No more research is required to know that these must happen. There are well known solutions, but now they really do need to happen with urgency, because committed global climate change gives us—and all species—no more time to act.

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Ensuring Co-benefits for Biodiversity, Climate Change and Sustainable Development

Risa Smith, Oscar Guevara, Lauren Wenzel, Nigel Dudley, Valeria Petrone-Mendoza, Martin Cadena and Andrew Rhodes

Abstract Significant investments are required by Parties to the three Rio Conventions—Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Convention to Combat Desertification (UNCCD), as well as the United Nations 2030 Agenda for Sustainable Development (2030 Agenda), to meet the ambitious goals that countries have agreed to. When the development of national and subnational frameworks to meet global commitments are conducted in isolation, the opportunity is lost to: (1)

R. Smith (✉)
IUCN, World Commission on Protected Areas (WCPA), Galiano Island, Canada
e-mail: risa.smith.wcpa.iucn@gmail.com

O. Guevara
WWF, Bogotá, Colombia
e-mail: ojguevara@wwf.org.co

O. Guevara
IUCN, World Commission on Protected Areas (WCPA), Gland, Switzerland

L. Wenzel
IUCN, World Commission on Protected Areas, Silver Spring, USA
e-mail: lauren.wenzel@noaa.gov

N. Dudley
Equilibrium Research, Gland, Switzerland
e-mail: nigel@equilibriumresearch.com

N. Dudley
School of Earth and Environmental Sciences, University of Queensland, Brisbane, Australia

V. Petrone-Mendoza
Comisión Nacional de Áreas Naturales Protegidas, Mexico City, Mexico
e-mail: valeria.petrone@conanp.gob.mx

M. Cadena
UNDP, Mexico City, Mexico
e-mail: martin.candena@undp.org

A. Rhodes
Pronatura Mexico, Mexico City, Mexico
e-mail: andrew.rhodes@pronatura.org.mx

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leverage co-benefits from the same investment; (2) use resources more efficiently; and (3) ensure that one action does not negatively affect another policy priority. For example, investments in greenhouse gas reduction have the potential either to positively impact biodiversity and sustainable development, or to result in unintended negative consequences; chances of positive synergies are greatly increased by cooperation and joint policy, planning and implementation. The challenge now is to learn lessons from the vast and diverse number of approaches being tried around the world and to enhance co-benefits. This paper describes the major inter-linkages between global commitments for conservation and development. It demonstrates the importance of enhancing synergies among global agreements and avoiding unintended and negative consequences, particularly on biodiversity, by providing examples of best practices and describing some of the pitfalls that occur when implementation of one agreement does not explicitly seek to enhance co-benefits with other agreements. In conclusion, the paper presents the case for the central role of nature-based solutions in simultaneously attaining global commitments for biodiversity, climate change and sustainable development.

Introduction

The world is at cross-roads with the convergence of several crises: catastrophic climate change, the sixth mass biodiversity extinction event, land degradation on a massive scale (Ripple et al. 2017) and increasing economic inequality in spite of a reduction in extreme poverty (World Bank 2016). Despite bold global commitments, and some specific successes, progress on all of these issues has been too little and too slow.

The United Nations Convention on Biological Diversity (CBD), Framework Convention on Climate Change (UNFCCC), Convention to Combat Desertification (UNCCD) and the 2030 Sustainable Development Agenda and its associated Sustainable Development Goals (SDGs), all recognize, in various decisions, the inter-linkages between their agreements and the benefits of co-implementation. While commitments have been made to enhance synergies, co-implementation has proven to be difficult in practice and negative impacts on biodiversity in particular, from implementation of other priorities, frequently occurs.

The cost of fully implementing the Aichi Biodiversity Targets of the CBD, the Paris Agreement of the UNFCCC, the SDGs and the UNCCD's target of land degradation neutrality (LDN) is estimated at hundreds of billions of dollars per year until 2030 (CBD High-Level Panel 2014; Stern 2015; Schmidt-Traub 2015). The sheer scale of investment required is argument enough to ensure that progress towards one goal does not hamper progress towards another. Add to that the inter-relatedness of these goals and enhanced effectiveness and efficiency that could be gained from working in concert across issues, and the need to develop ways for effective co-implementation becomes obvious (Science for Environmental Policy 2015; Cadena et al. 2017; Quéré et al. 2014; Executive Secretary of Convention on Biological Diversity 2017; Schultz et al. 2016; Steiner 2017). Despite some notable exceptions, and efforts at the global level, there is little consistency or cross-referencing between global goals (Bodin and Santamari 2016). Potential approaches have been proposed, including enhancing resilience thinking (Cadena et al. 2017; Schultz et al. 2016), the ecosystem approach (Bodin and Santamari 2016; Epple et al. 2016), the landscape approach (Sayer et al. 2013), landscape management (Peterson 2011) adaptive management (Epple et al. 2016), ecosystem-based adaptation (Herr and Landis 2016) and using the CBD's National Biodiversity Strategies and Action Plans as mechanisms to foster integrated thinking (Cadena et al. 2017; Executive Secretary of Convention on Biological Diversity 2017). Even from the perspective of climate change goals alone, taking an integrated approach is essential, including for enhancement of carbon sinks in terrestrial and coastal sectors (IPCC 2014) and placement of renewable energy infrastructure (Science for Environmental Policy 2015). Yet at the national and regional levels there are relatively few successful examples of attaining co-benefits.

Many countries and organizations have already emphasized the importance of taking measures that maximize synergies among global goals and minimize negative impacts and externalities (Bodin and Santamari 2016) [i.e. tackling Aichi Biodiversity Targets on protected areas and ecosystem degradation and specific Sustainable Development Goals (Brooks et al. 2015)]. These provide valuable principles to guide countries towards co-implementation and co-measurements of success. The need now is to go beyond principles and to develop the capacity and concrete tools for making decisions that enhance implementation of global commitments, at different scales, without creating undesirable impacts and unnecessary trade-offs. As 2020 approaches, and progress towards biodiversity, climate change and sustainable development goals are assessed, the importance of turning principles into concrete decision-making tools has become urgent.

In this paper, we analyze—through different approaches—major convergence points between the Rio-Conventions and the 2030 Agenda, exploring entry points that can be useful to regional, national and subnational efforts to increase co-implementation and avoid potential trade-offs.

Biodiversity and Nature-Based Solutions to Climate Change Mitigation

1. *Terrestrial Ecosystems*

To keep global temperature rise this century well below 2 °C, relative to pre-industrial levels, emissions of greenhouse gases into the atmosphere must be reduced by 50–70% by 2050 and to zero by 2100 (IPCC 2014). Several actions will have to be taken simultaneously: (i) reduction and eventual phase-out of fossil fuels; (ii) reduction of emissions from land use and land use change; (iii) removal of carbon dioxide from the atmosphere (The Economist 2017; Rockström et al. 2017; IPCC 2014); and (iv) maintenance of natural carbon sinks and storage (Rockström et al. 2017). Recognizing that Land Use, Land-Use Change and Forestry (LULUCF) account for approximately 24% of total greenhouse gas emissions—almost equivalent to energy and heat production (25%) and more than transportation (16%) or industrial activity (21%) (Thompson 2014)—the Paris Agreement on Climate acknowledges that nature-based solutions will play an important role in reducing greenhouse gas emissions (see Article 5, UNFCCC 2015). The necessity of this approach has been reinforced by the International Declaration on Nature-Based Solutions for Water Management Under Climate Change (Marrakech Partnership et al. 2017), the RED-PARQUES Declaration (REDPARQUES 2015b), the inclusion of nature-based solutions in some—albeit only a few—Nationally Determined Contributions (NDCs) to climate change (Laurans et al. 2016) and in the scientific literature (Rockström et al. 2017). According to some estimates, nature-based solutions to climate change, such as restoration of forests, wetlands, grasslands and agricultural lands, afforestation and protection of ecosystems that are currently sequestering and storing carbon, could reduce greenhouse gas emissions by as much as 37% by 2030 (Griscom et al. 2017). In the interest of advancing an integrated approach the CBD, at its thirteenth Conference of the Parties, expanded the sectors in which it intends to mainstream biodiversity to include energy and mining, manufacturing, processing and health sectors (CBD 2016).

One important feature of nature-based solutions to climate change mitigation is that LULUCF can reverse the negative impacts of past activities (UNFCCC 2014). Carbon stocks in forest biomass decreased by an estimated 0.22 Gt annually from 2011–2015, mainly because of a reduction in forest area. Through better forest management, forest restoration and afforestation these losses can be reversed.

Brazil's NDC to the Paris Agreement provides an example of how nature-based solutions can be integrated into climate change mitigation. Brazil aims to reduce greenhouse gas emissions by 37% below 2005 levels by 2025, through the implementation of policies that also build resilience of populations, ecosystems, infrastructure and production systems, by reducing vulnerability, and through the provision of ecosystem services [Federative Republic of Brazil (FRB) 2016].

2. *Marine Ecosystems*

Oceans, including coastal ecosystems, have sequestered approximately 30% of the carbon dioxide in the atmosphere since pre-industrial times (Thompson 2014). Blue carbon—the carbon stored in mangroves, salt marshes and seagrasses—is a major carbon sink, covering less than 20% of the total ocean area, but accounting for approximately half of the total carbon sequestered and stored in marine sediments. These habitats are found on every continent except Antarctica and combined cover 49 million hectares (The Blue Carbon Initiative 2017).

The role of coastal ecosystems in climate change mitigation is better understood than open ocean ecosystems, and is often included in calculations of the importance of ecosystems in climate change mitigation (Duarte et al. 2013; Roberts et al.

2017; Epple et al. 2016). For example, the loss of vegetated marine habitats, such as seagrasses, salt-marshes, macro-algae and mangroves is estimated to result in a net emission of 1 Gt CO_2 per year (Duarte et al. 2013). This compares to the 4.9 Gt annual emissions from land use change, including forestry (Griscom et al. 2017). IUCN estimates that if half of the annual coastal wetlands loss was halted, emissions would be reduced by a 0.23 Gt CO_2 per year (Herr and Landis 2016)—equivalent to taking 50,000 cars off the road (calculated from US Environmental Protection Agency 2017). Although the potential for forest activity to sequester carbon is greater than for coastal marine habitats, the coastal marine habitats provide a significant contribution and their importance to biodiversity is equal to that of forests (Duarte et al. 2013; Herr and Landis 2016).

As of 2016 only 28 countries had included coastal wetlands as part of their NDCs for climate change mitigation, most of which specifically refer to mangrove protection, conservation and restoration. More widespread inclusion of coastal wetlands in NDCs would have significant co-benefits for both biodiversity and sustainable development (Herr and Landis 2016).

Ocean acidification is increasingly recognized as a carbon-driven problem threatening ocean food webs, food security and livelihoods. Since the industrial revolution, the acidity of ocean water has increased by about 30%, potentially threatening shell-building marine life, including phyto- and zoo-plankton, which are the base of the marine food web (Pacific Marine Environmental Laboratory Carbon Program 2017). The need to reduce ocean acidification is prominent in both the SDGs and the Aichi Biodiversity Targets, further highlighting the need to integrate efforts.

Marine protected areas (MPAs) can enhance the ability of the oceans to sequester more carbon without increasing ocean acidification and without negatively impacting marine species. There are two mechanisms by which this can occur. First, fish excrete ammonia or ammonium through their gills, making the most bioavailable form of nitrogen available to primary producers, which in turn sequester CO_2 from the atmosphere. Enhanced fish populations, which are protected from overfishing in MPAs, will make more nitrogen available, resulting in increased primary productivity. This effect can be significant. One study showed that nitrogen cycling can be enhanced by four to fivefold in unfished sites compared to fished sites. The second mechanism by which marine systems can increase carbon sequestration is just beginning to be better understood. Fish are known to affect the marine inorganic carbon cycle by calcifying carbon in their guts and excreting carbonate [i.e. calcified carbon], much of which ends up as stored carbon in marine sediments. However, information is lacking on several aspects of this process, making it difficult to determine its overall contribution to removal of atmospheric CO_2 (Roberts et al. 2017).

Just as deforestation results in CO_2 emissions to the atmosphere, activities that disturb the ocean floor, such as bottom trawling and seabed mining, can readily remobilize stored CO_2 with unknown consequences to the marine carbon cycle. MPAs have the potential to serve as a valuable tool to manage these impacts.

All nature-based solutions to reduce greenhouse gases emissions and improve carbon sequestration can have an impact on biodiversity and on the livelihoods and well-being of people who depend on biodiversity. There is no magic, one-size-fits-all tool that will ensure that decisions to meet one goal do not have a negative impact on others. At the project assessment level, a decision-screen that weighs impact and maximizes all benefits is needed.

The Relationship Between Biodiversity and the Sustainable Development Goals

Biodiversity is relevant to all SDGs, including those that do not directly reflect the Aichi Biodiversity Targets. An overview of the importance of the 2030 Agenda for Sustainable Development, and associated SDGs, as an enabling environment for the achievement of the Aichi Biodiversity Targets has been provided by the Convention on Biological Diversity (Executive Secretary of Convention on Biological Diversity 2017; Schultz et al. 2016). Briefly, achieving the SDGs addresses the drivers of biodiversity loss, builds the institutional capacity for governing biodiversity and aids in mainstreaming biodiversity through recognition of the ecosystem services provided by biodiversity (Schultz et al. 2016). Aware of the strong links between the SDGs and the Aichi Biodiversity Targets, the 13th Conference of the Parties (COP 13) to the CBD decided that Parties and all relevant stakeholders should integrate and mainstream biodiversity into implementation of the SDGs.

The Relationship Between Land Degradation Neutrality and Other Biodiversity and Climate Targets

The UNCCD has made land degradation neutrality [LDN] the central focus of its global strategy, recognizing the health of the land as a unifying theme that influences biodiversity, human livelihoods and climate change in equal measure. The SDGs explicitly support attainment of LDN in SDG 15.3, to: “combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation neutral world”. Attaining LDN implies a drastic reduction in land use change such as deforestation and loss of natural grasslands, which in turn has positive impacts on climate change mitigation and biodiversity conservation.

Mitigating Climate Change, Safeguarding Biodiversity, Reducing Land Degradation and Supporting Sustainable Development Goals

1. *Spatial Planning*

Spatial planning—on both land and in the ocean—is the first step to enable integrated thinking across a landscape. There are good examples of how spatial planning can work for safeguarding or enhancing biodiversity, mitigating climate change and taking into account sustainable development. Several European countries have implemented a project screen for renewable energy projects in which sensitivity mapping locates important biodiversity areas, including protected areas, and avoids these when locating wind or solar energy infrastructure (Science for Environmental Policy 2015). German law prevents the siting of renewable energy infrastructure at locations that conflict with conservation goals (Peschel 2010). In response, the German Solar Industry Association, in conjunction with the German Society for Nature Conservation, has drawn up criteria to guide nature-friendly solar development (Peschel 2010). Solar photovoltaic arrays and wind installations—both of which are important for reducing fossil fuel use—are situated to avoid protected areas and carbon sequestering ecosystems, retain trees and hedges, avoid disturbance of birds and bats during breeding season and surrounding vegetation is managed for the benefits of wildlife.

South Africa has taken a landscape approach in which sensitivity mapping, at various scales, identifies protected areas, endangered ecosystems and ecological support areas needed to maintain resilient ecosystem services. This spatial mapping allows for the identification of appropriate areas for production, development and conservation, thus implementing CBD, UNCCD, UNFCCC and the SDG goals, with one comprehensive process (Peterson 2011).

Supported by spatial mapping, several tools are available to facilitate decisions that provide multiple benefits. At a global or national scale, Key Biodiversity Areas (KBAs) are "sites contributing significantly to the global persistence of biodiversity" and therefore help to plan development in ways that minimize negative impacts on biodiversity (IUCN 2016a). Similarly, the identification of High Conservation Value Areas (HCVA) is a tool widely used in landscape mapping, conservation and natural resource planning and advocacy. Its six values cover environmental and social priorities shared by a wide range of stakeholders (Senior et al. 2015). The many gap analysis tools available, such as the USGS Gap Analysis Program (USGS 2017), help to maximize the effectiveness of protected area networks by locating protected areas in the most suitable locations for multiple benefits. IUCN has developed a framework for countries to rapidly identify areas suitable for forest landscape restoration—Restoration Opportunities Assessment Methodology (ROAM). This tool allows for optimizing positive impacts of land use transitions on key ecosystem services, including carbon sequestration, the provision of hydrological services, water yield and sediment retention and nutrient retention (IUCN 2016b).

It is important to note that spatial planning is somewhat controversial because its use can make trade-offs among different values and sectors more immediate and tangible. For this reason, it is essential to build in robust stakeholder and public participation into planning processes.

2. *Land and Freshwater Management*

Once spatial planning has identified current land and water use, and made proposals about future uses, many land management tools are available to protect multiple values across a landscape.

Protected Areas and Other Effective Area-Based Conservation Mechanisms (OECM)

The pivotal role that connected, well-funded, well-managed protected areas play in supporting not only biodiversity goals, but also sustainable development and climate change goals, is increasingly recognized (Nature Needs Half 2017; Ripple et al. 2017; REDPARQUES 2015a; Dudley et al. 2010, 2014, 2017; Secretariat of the Convention on Biological Diversity 2016). About 312 Gt of CO_2 are stored in the world's protected area network, equivalent to 15% of the world's terrestrial carbon stock (Dudley et al. 2010).

Emerging information supports the benefits of well-planned and managed protected areas in implementation of the SDGs. For example, in Costa Rica and Thailand, districts adjacent to protected areas experience 10 and 30% less poverty, respectively, than districts without protected areas (Turner et al. 2012). The natural ecosystems maintained by protected areas contribute to a range of ecosystem services, including food and water security, disaster risk reduction and health and recreational services and the economic values of these are increasingly being recognized.

REDPARQUES (Latin American Technical Cooperation Network on National Parks, and other Protected Areas and Wildlife) is a unique network of protected area agencies that seeks to improve the management of national parks and other protected areas through technical cooperation and the exchange of knowledge and experience among its 19 member countries. One of the unique elements of REDPARQUES is that it has expanded recognition of the importance of protected areas in mitigation of and adaptation to climate change, thereby providing a model for using protected areas to attain multiple goals. The Amazon Vision, one of the REDPARQUES partners, includes an initiative on "Protected Areas, Natural Solutions against Climate Change (NASCC)". This initiative recognizes that protected areas are key to building resilience to mitigate the impacts of a changing climate, to ensuring the provision of ecosystem services on which people depend and to protecting biodiversity (REDPARQUES 2015a; Suarez et al. 2015). The Amazon Vision makes extensive use of spatial mapping to identify climatic conditions, climate risk and opportunities to enhance resilience in the Amazon's protected areas network. This tool provides a foundation for decisions on management of existing protected areas and creation of new ones that include multiple goals and values and facilitates a climate smart-landscape approach to other agendas, including participatory land use planning and the development of infrastructure (Suarez et al. 2015).

Global efforts to encourage different forms of conservation management, which allow for economic activity without losing the ecosystem values of the natural systems, could lead to recognition of new types of protected areas and the prevention of carbon-emitting land conversions such as deforestation. Furthermore, the potential of conservation outside the protected areas network is gaining increasing recognition. The initially confusing wording of Aichi Target 11, which referred to "protected areas and other effective area-based conservation measures" has been the trigger for debate on the definition and recognition of a set of sites that, whilst not being full protected areas or having nature conservation as a primary aim, are nonetheless managed in ways compatible with the long-term maintenance of biodiversity, reduction of land degradation and integration into climate change strategies (Laffoley et al. 2017). Indigenous conservation areas could play a previously unrecognized role, as could watershed protection areas, well-managed forestry and traditional grazing areas. Tenure-secure indigenous forest lands—some of which would be considered conservation areas—in Bolivia, Brazil and Colombia are equivalent, in terms of carbon sequestration, to taking 9–12.6 million passenger vehicles off the roads for a year (Watts 2017).

The potential for leakage highlights the importance of considering the effects of protected areas creation and other conservation actions such as logging bans across different spatial scales. Leakage happens when the creation of protected areas in one location leads to compensatory increases in habitat loss in another. For example, in South East Asia, some countries have reversed the trend of conversion of natural forests through strong policies and enforcement. In neighboring countries, where policies, enforcement and governance are weaker, the pressure for conversion of natural forest lands, particularly to agriculture, has increased (Leadley et al. 2016; Bodin and Santamari 2016).

Ecosystem Restoration

Given the significant contribution of degraded or converted natural ecosystems to greenhouse gas emissions, many people have turned their attention to ecosystem restoration as part of the solution to climate change mitigation. Opportunities exist in drylands to halt and reverse desertification, in agricultural lands to increase carbon in soils as a climate mitigation strategy and also to reduce soil erosion, and in restoration of peat and other wetlands for multiple ecosystem functions. It is estimated that restoration of degraded forests, grasslands and wetlands could reduce greenhouse gas emissions significantly by 2030 (Leadley et al. 2016; Griscom et al. 2017), ensure habitat for species, including those at risk and provide an array of ecosystem services, such as disaster risk reduction and provision of fresh water. However, despite a plethora of guidance on how to restore specific ecosystems (Society for Ecological Restoration 2012), there is still a net loss of forests and ecosystems that sequester and store carbon (Secretariat of the Convention on Biological Diversity 2014).

Although ecosystem restoration was originally intended as a process to restore ecosystems to their historical state (Society for Ecological Restoration 2012), in more recent years the term has also been used more loosely to describe reforestation or afforestation efforts that might aim to gain carbon sequestration potential without considering other ecosystems services and biodiversity. Reforesting with monocultures of exotic species falls into this category, where reforested area may indeed sequester carbon, while being detrimental for biodiversity (Ferez et al. 2015). Furthermore, climate change increases the possibility that restoration to an “original” state is impossible from a practical perspective and that restoration to a new but ecologically functioning ecosystem may be more realistic.

The New York Declaration on Forests—an update of the Bonn Challenge—aims to bring 150 million hectares of degraded and deforested land into restoration by 2020 and 350 million hectares by 2030. This declaration recognizes that these restoration efforts have to be implemented with national priorities in mind, such as water and food security, rural development, climate change, biodiversity and land degradation neutrality. As of September 2016, commitments for forest restoration under this initiative include 63.3 million hectares in Africa, 23.6 million hectares in Latin America and 22.4 million hectares in Asia (Bodin and Santamari 2016).

Investments in ecosystem restoration have increased over the past few years on all continents (Bodin and Santamari 2016). It is time to measure the successes and challenges from existing approaches in attaining co-benefits for biodiversity, climate change and sustainable development.

REDD+

Some initiatives originally intended for climate change mitigation have been expanded to include biodiversity conservation. Reducing emissions from deforestation and degradation (REDD) in developed countries was expanded in the Bali Action Roadmap to include conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+) (Harvey et al. 2010). REDD+ supports climate change goals as well as conservation and sustainable development goals articulated in the Aichi Biodiversity Targets and SDGs. Some of the ways in which REDD+ now supports multiple goals are: the expansion of the eligibility for funding to countries with historically low deforestation; use of criteria that ensures REDD+ does not result in the conversion of natural forests to plantations, exotic monocultures or non-forested systems; use of criteria to prevent leakage—ensuring that protecting forests in one place does not result in deforestation in another place; and prevention of funds to projects with questionable mitigation benefits and few or no biodiversity benefits (e.g. palm plantations) (Harvey et al. 2010).

Many REDD+ projects have already demonstrated the benefits of this new approach, including: the Taita Hills Project in Kenya, which generates carbon offsets for the protection of forest and savannah outside Tsavo National Park; the Rukinga Wildlife Sanctuary, also in Kenya, which provides income to the community, government and local landlords for avoiding greenhouse gas emissions from deforestation (IPCC 2014). A model looking at the potential for REDD+ to positively affect biodiversity, demonstrated that in Brazil the number of threatened species could be reduced to 6 species from 311 by simply enforcing Brazil's new Forest Code (Mead 2016), which is now known as the Law of Native Vegetation Protection (LNVP).

Mangroves are now eligible for REDD+ funding, and efforts are underway to establish a voluntary carbon standard to create sustainable financing for other blue carbon habitats.

3. *Management of Marine Systems*

The development of the SGDs and the increasing recognition of the role of oceans in regulating global climate offer important opportunities to better integrate coastal and ocean management with climate mitigation efforts. In addition, the dramatic impacts of climate change on ocean ecosystems, such as the increase in ocean surface temperature, acidification, shrinking of Arctic sea-ice and sea-level rise, will have significant impacts on global food security, biodiversity and risks from disasters (IPCC 2014; Melillo et al. 2016).

Many tools described above for land management—protected areas, ecosystem restoration and spatial planning—are also being applied in coastal and ocean systems. Five per cent of waters under national jurisdiction are now protected (UNEP-WCMC and IUCN 2016) and the United Nations is considering governance mechanisms for managing biodiversity in areas beyond national jurisdiction—the 60% of the planet known as the high seas.

4. *Enabling Policy*

Large scale replacement of fossil fuels with renewable energy is a component of most scenarios to attain climate change goals (IPCC 2014). This approach could be positive or negative for biodiversity and sustainable development, depending on how it is implemented. Tools for identifying trade-offs and minimizing negative impacts are clearly needed. For example, an increase in bioenergy, coupled with carbon capture and storage (BECCS), is prominent in most scenarios that result in attainment of the Paris Agreement. However, a massive increase in bioenergy would require land use change, including the conversion of natural habitats to agriculture and existing agricultural area from food production to bioenergy production. Land use change on the scale required would result in negative impacts on both biodiversity and SDGs (Leadley et al. 2016). The same trade-offs are apparent in planned increases in hydro-electric power, which can result in deforestation, loss of aquatic habitat (Charity et al. 2016) and the release of CO_2 and methane (Deemer et al. 2016; Scherer and Pfister 2016).

Some countries have enshrined the importance of multiple benefits in law. The German Renewable Energy Sources Act only allows installations of solar parks on land that has been previously disturbed such as by farming or military use. Ideal sites include brownfield and degraded land—creating so-called “brightfields”.

Increases in economic activity, related to SDG Goal 8 on “decent work and economic growth”, has the potential to result in policies and activities that encourage economic activity at the expense of biodiversity conservation and climate change mitigation and adaptation. An example of this is the 134,866 km of fossil fuel pipelines currently under construction or planned (Tubb 2017) in countries that are Parties to the Paris Agreement on Climate Change in North America (Canada, U.S., Mexico), South America (Brazil, Peru, Colombia), Middle East (Iran, Oman), Russia, Eastern Europe (Turkey), Western Europe (U.K., Denmark, Norway) and Asia (China and India). Given limited financial resources, investments in fossil fuel infrastructure tie up funds that could otherwise be used for renewable energy.

Provision of positive incentives for conservation, climate change and sustainable development, and removal of harmful subsidies, will go a long way towards mobilizing resources for change (Ripple et al. 2017; Secretariat Convention on Biological

Diversity 2010; United Nations 2015). A focus on incentives for implementing nature-based solutions is a highly cost-effective approach. This would include 'strong financial impetus' for afforestation on degraded land, reforestation on converted forest land, restoration of carbon sequestering ecosystems and protection of carbon storing ecosystems (Rockström et al. 2017).

A successful model for mobilizing resources for positive outcomes is the Biodiversity and Protected Areas Management Programme (BIOPAMA). This is a partnership between IUCN and Joint Research Center of the European Commission (EC-JRC). BIOPAMA addresses threats to biodiversity in African, Caribbean and Pacific (ACP) countries, while reducing poverty in communities in and around protected areas. BIOPAMA has had significant success in building the capacity to manage protected areas for multiple values and to improve access to science, knowledge and data that enhances decision-making on biodiversity conservation and sustainable development (BIOPAMA 2016).

Another entry point for enabling policy is to overcome the traditional sectorial silos and avoid tensions and potential trade-offs between different policies (e.g. an increase in deforestation rate due to a policy of agricultural expansion). A shift on the focus of a sectoral perspective of issues in a country's administration into a more holistic one requires policy changes. The SDGs address this systemic issue and encourage Parties to enhance Policy Coherence for Sustainable Development (PCSD). A useful framework to progress on PCSD has been developed by the OECD providing general guidance to: (1) conduct analysis to identify policy coherence issues; (2) align existing institutional mechanisms for policy coherence to other environmental and development agendas; and (3) consider key elements for tracking progress on policy coherence for sustainable development (OECD 2016).

Conclusions

The world is currently focused on the imperative to reduce atmospheric greenhouse gases and avoid catastrophic climate change. However, the loss of biodiversity and associated ecosystem services, the loss of land and soil resources, the decline of global fisheries and the plight of the world's poorest citizens are equally pressing issues. Given the scale of financial resources required, avoiding unanticipated negative consequences, and finding solutions that enhance synergies are necessary.

The large number of solutions being tried at different scales around the world amount to a global experiment in integrated thinking. The task now is to pull together the lessons learned from the many diverse approaches and actors, and turn them into practical tools that will allow countries to effectively meet their global commitments. A focused effort to integrate the work of the three Rio Conventions with the Sustainable Development Goals has long been discussed; it is now in urgent need of implementation. Unique and sometimes difficult partnerships have to be forged, including among conservationists, poverty-reduction advocates, industries and those concerned with climate change policy.

We demonstrate that among the examples presented, spatial planning, protected areas and ecosystem restoration are distinguished by the multiple benefits they provide—benefits that go far beyond their primary purpose. We also show that nature-based solutions provide an essential tool in tackling several global problems simultaneously. While a few countries have already identified nature-based solutions in their NDCs to the Paris Climate Agreement, and some countries have developed guidelines or legal instruments to ensure that co-benefits are obtained, more countries need to include nature-based solutions in their tool kits to tackle climate change.

This paper has identified the problem and provided suggestions and examples that support a co-benefits approach to implementing multiple agreements. Future work of global organizations such as the International Union for the Conservation of Nature (IUCN) needs to draw on successful approaches already in use, as well as the results of policy and scientific research, to develop comprehensive guidance for simultaneously protecting biodiversity, addressing climate change and implementing the SDGs.

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Sustainable Hydropower: Using Ecosystem-based Adaptation to Increase Local Adaptation Capacity in Brazil

Katia Cristina Garcia, Alexandre Mollica, Denise Ferreira de Matos and Luciana Rocha Leal da Paz

Abstract Recent observed changes in climate patterns in Brazil has increased the importance of ecosystem-based adaptation (EbA) in order to reduce the effects of drought and floods. The energy (hydropower) sector is specially starting to be affected by those changes. Changing rainfall patterns, rising temperature, droughts and extreme weather events may affect hydroelectricity generation, causing damages to the infrastructure or disruptions in service. EbA is mentioned in the Brazilian NDC, highlighting the need to increase national capacity in water security (National Water Security Plan), conservation and sustainable use of biodiversity (NBSAP). In addition, the Energy Sector Strategy of the NAP mentions the environmental issues, especially regarding the protection and recovery of natural resources (fauna, flora and physical environment). This paper discusses how the hydropower generation in Brazil can shift to a sustainable hydropower pattern, capable of dealing with climate change issues and, additionally, contributing to increase local adaptation capacity using an ecosystem approach, as accorded on Paris Agreement. A set of EbA measures are presented as opportunities to reduce the climate vulnerability and/or increase the resilience of local ecosystems and of the communities depending on them, where hydropower projects are installed or are being planned.

Hydropower Generation, Biodiversity and Climate Change

Concerns about the protection and conservation of biodiversity have been gaining more attention in international political discussions. As one of the richest countries in the world in terms of biodiversity, with high rates of endemism (MMA 1998), Brazil has been engaged in the international context and has been developing strategies, plans and programs adapted to its needs and reality. Among the major international

K. C. Garcia (✉) · A. Mollica · D. F. de Matos · L. R. L. da Paz
Energy Optimization and Environment Department, Electric Power Research Center (CEPEL), Eletrobras Group, Av. Horácio de Macedo, 354, Cidade Universitária, Ilha do Fundão, Rio de Janeiro, RJ 21941-911, Brazil
e-mail: garciak@cepel.br

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biodiversity-related conventions ratified by Brazil, we mention The Ramsar Convention on Wetlands of International Importance, Convention Concerning the Protection of the World Cultural and Natural Heritage, Convention on International Trade in Endangered Species of Wild Fauna and Flora and the Convention on Biological Diversity (CBD).

Parallel to the growing concerns about biodiversity protection and conservation, there is also an increase in global energy demand (EIA 2015). With this growth, the pressure on biodiversity is also expected to increase. In Brazil, part of the projected demand for electricity will be supplied by the expansion of hydroelectricity (Brazil, MME/EPE 2015). A major issue is that many of the sites that have potential for hydroelectric generation expansion also have a high value in terms of biological diversity with sensitive ecosystems and with local communities that depend on these ecosystems as food suppliers or as a source of income, which means, in other words, an overlap problem (Table 1).

A number of important negative impacts to biodiversity are particularly related to generation plants as well as transmission and distribution infrastructure, which may occur during the implementation or operation phases. Table 2 indicates some possible direct and indirect impacts of electricity generation, transmission and distribution activities to biodiversity, identified in environmental studies in Brazil.

Nowadays, impacts related to hydroelectricity are considered in several planning stages, from long term planning studies (30 years) to the 10-year expansion plan, and especially in the project phase, when requiring environmental permits. However, these evaluations focus on minimizing/controlling each impact, rather than the cumulative impacts of other activities in the basin. Moreover, none of these studies assess neither how the biodiversity could be affected by possible climate changes, nor how local populations could be affected with a possible loss of biodiversity, and hence of the environmental services. As a consequence, such populations may become even more vulnerable.

The main objective of this paper is to propose the use of the so-called "climate lens" and "lens of ecosystems" when assessing the impacts at all levels of the expansion and operation planning of electric power generation, and more specifically of the hydroelectricity plants. These aspects are not only aimed at minimizing/controlling the impacts of energy generation, taking into account the current and future vulnerability of the region, but also defining a set of programs that can contribute to increase the capacity of adaptation of these sensitive areas. Minimizing environmental impacts is an important vector of resilience that also relates to the concept of Ecosystem-based Adaptation (EbA), defined first at the Convention on Biological Diversity.

Ecosystem-Based Adaptation (EbA) is defined as the use of ecosystem management, conservation and restoration, to provide ecosystem services that enable society to adapt to the impacts of climate change. EbA can have many positive impacts on biodiversity and on local communities (Fundação Grupo Boticário 2015), such as:

Table 1 Main international conventions related to biodiversity ratified by Brazil (Garcia 2007)

Conventions	Year	Biodiversity Aspects covered by the Convention	Brazilina Legal Framework
RAMSAR: The Ramsar Convention on Wetlands of International Importance	1971	Maintenance of ecosystems integrity and the provision of goods and services provided by ecosystems	Legislative Decree No. 33 of June 16, 1992, and promulgated by the President of the Republic by Decree No. 1905, dated May 16, 1996
Convention Concerning the Protection of the World Cultural and Natural Heritage	1972	Protection, conservation and presentation of the cultural and natural heritage	Legislative Decree No. 74 of June 30, 1977, ratified on December 2, 1977 and promulgated by Decree No. 80,978 of December 12, 1977
CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora	1973	Reduction of losses of biodiversity components (biomes, habitats and ecosystems, species and populations, genetic diversity)	Legislative Decree No. 54 of June 24, 1975, and promulgated by Decree No. 92,446 of March 7, 1986. The provision on the implementation of CITES in the country is established in Decree 3607 of September 21, 2000
UNCLOS: The United Nations Convention on the Law of the Sea UNCLOS	1982	Maintenance of ecosystems integrity and the provision of goods and services provided by ecosystems	Legislative Decree 05 of November 9, 1987. Decree 1530 of June 22, 1995 declares the entry into force of the Convention on November 16, 199
CBD: The Convention on Biological Diversity	1992	Reduction of losses of biodiversity components (biomes, habitats and ecosystems, species and populations, genetic diversity) Promotion of the sustainable use of biodiversity	Legislative Decree No. 2 of February 8, 1994, and promulgated by Decree No. 2519, on March 17, 1998

- the reduction of local vulnerability to impacts associated with gradual and extreme events caused by climate change;
- economic, social, environmental and cultural benefits;
- improvement of ecosystem conservation, ecological maintenance;
- ecological integrity of ecosystems;
- carbon sequestration;
- positive effects on food security;
- sustainable water management; and
- the promotion of an integrated vision of the territory.

In summary, EbA deals primarily with the sustainable management, conservation and restoration of ecosystems, taking into account climate change and its impacts, in order to reduce vulnerability and improve the resilience of such ecosystems and the local community. EbA addresses climate change, biodiversity, ecosystem services,

Table 2 Possible direct and indirect impacts on biodiversity by the activities of the electricity sector (Eletrobras 2013)

Direct Impacts	Indirect Impacts	Atividade	Tipo de Empreendimento
Water Quality Change	Impact on flora and fauna	Energy generation	Hydroelectric Power Plants Thermonuclear Plant
Loss of Vegetation Cover	Fragmentation and border effect Impact on fauna	Energy generation Energy transmition	Hydroelectric Power Plants Wind farms Transmission and Distribution Lines
Changes in habitats	Changes in fauna and flora communities	Energy generation Energy transmition	Hydroelectric Power Plants Thermoelectric Power Plants Transmission lines
Interference in fauna and flora	Changes in ecological processes	Energy generation Energy transmition	Hydroelectric Power Plants Thermoelectric Power Plants Wind farms Transmission lines
Interference on migratory routes of aquatic fauna	Population reduction Reduction of genetic diversity	Energy generation	Hydroelectric Power Plants
Interference in migratory routes and collision with birds	Population reduction Reduction of genetic diversity	Energy generation Energy transmition Energy Distribution	Wind farms Transmission and Distribution Lines

and sustainable resource management, and is more effective when local community is involved. UNDP highlights some examples of EbA:

- tree planting with high water retention capacity in drought areas;
- identification and planting of species to reduce erosion and landslides;
- maintenance of ecosystem connectivity;
- preservation or restoration of sensitive areas;
- natural resource management to ensure maximum benefit to communities.

We believe that projects and actions aligned with the concept of EbA can be encouraged when building and operating hydroelectric plants in regions with high environmental sensitivity. Plants that have a long-term vision of environmental conservation can present a set of EbA measures from the construction phase to the operation phase, aiming the maintenance of biodiversity and ecosystem services, which can help the local populations to adapt to possible adverse impacts of climate change.

Guidelines from the International Association for Impact Assessment (IAIA) stress that "*(…) impact assessment (IA) can ensure that the design of policies,* *plans, programs and projects adequately take into account mitigation of changes (the effects of the proposal on greenhouse gas emissions), and adaptation to climate change (effects of climate change on the proposal). Taking climate change into account in decisions, through IA, can help reduce vulnerability to climate change, thereby improving the resilience of natural and human systems (…)*". This means that IA can help and also play a significant role in achieving national, regional or sectoral climate change objectives (IAIA 2013).

According to the IPCC (2014), adaptive capacity is the ability of a system to adjust to climate variability and extreme weather and weather events, mitigating possible damage and taking advantage of opportunities or dealing with consequences. It depends on two variables: vulnerability and resilience. The lower the vulnerability of a system and the greater the resilience, the greater its potential for adaptation (IPCC 2014).

Adaptation to climate change is the process of adjusting to the current or future climate and its effects (IPCC 2014). In human systems, adaptation seeks to mitigate, avoid harm or explore beneficial opportunities. In natural systems, human intervention can facilitate adjustment to the future climate and its effects. There are a number of approaches to adapting to climate change, such as the hazard-based approach, risk management, vulnerability studies, resilience-based approach, and the Ecosystem-Based Adaptation (EbA), discussed in this paper.

EbA and the International Agreements Ratified by Brazil

Despite been neglected in the past as a viable tool for adaptation and mitigation, EbA is gaining more recognition in the international climate policy scene since the Paris Conference, when the focus began to rapidly shift from theory to action, mainly due to the commitments set out in the Intended Nationally Determined Contributions (INDC). EbA is mentioned in the Brazilian NDC, when the need to increase national capacity in water security it is highlighted (National Water Security Plan) and when the need for conservation and sustainable use of biodiversity is mentioned (National Strategic Plan for Protected Areas and the Brazilian Forest Code, in particular for Permanent Preservation Areas). In addition, the Energy Sector Strategy of the National Adaptation Plan (NAP), instituted in 2016, mentions the need to take into consideration the issues related to environmental legislation regarding the protection and recovery of natural resources (fauna, flora and physical environment) in the adaptation studies of the electricity sector.

The Brazilian NAP also presents an assessment of biodiversity and ecosystems loss considering several climate change scenarios. The adaptation options prioritized considering these scenarios were: use of ecosystem-based adaptation (EbA) in areas where the risk of extreme climate events is high; modelling consequences for biodiversity and ecosystem services caused by conservation, recovery and sustainable use of biodiversity public policies; and monitoring in 50 federal protected areas to assess in situ the current and future impacts of climate change on biodiversity.

EbA in Practice: Proposing and Measuring Efficiency/Effectiveness

According to the International Institute for Environment and Development (IIED/IUCN 2016), although many countries make commitments aligned with the concept of EbA, this rarely leads to clear goals and targets, which would allow an assessment of the effectiveness of adaptation measures over of time. Even where measurable targets are defined, it is unclear whether they will be enough to meet adaptation needs in the communities and ecosystems that are affected (IIED/IUCN 2016).

Some organizations around the world are evaluating the effectiveness of EbA measures for the development of robust adaptation plans, taking into account local economic interests as well as social and environmental needs, thus allowing greater access to funding for adaptation (IIED 2016).

In this sense, effective EbA measures should follow some basic principles (UNDP, s.d.):

- build actions based on good practices in integrated natural resource management;
- involve local communities;
- develop strategies with multiple partnerships (governments, communities, private sectors, NGOs, researchers, etc.) of diverse interests, such as conservation, development and poverty reduction; and
- integrate EbA with a broader context of adaptation.

From these basic principles, a methodology based on four components is proposed (UNDP, s.d.):

Component A: Define the context of adaptation, noting the possible climatic or non-climatic pressures on biodiversity, the ecosystem services, and the needs of local communities.
Component B: Development for change, which means planning the EbA actions that will be implemented, including the definition of its objectives and goals, as well as the indicators to be used to monitor the performance.
Component C: Implementation of the adaptation measures, including monitoring, data interpretation, evaluation and route adjustment (finishing the plan, do, check, act cycle).
Component D: Selection of appropriate adaptation measures according to the specific local context. The options can be grouped according to ecosystem services and their benefits, always aiming to maintain or increase resilience.

In order to be effective, actions should enable communities to maintain or improve their adaptive or resilient capacity and reduce their vulnerability to climate change, while improving co-benefits that promote well-being. Another aspect to consider is whether actions restore, maintain, or enhance ecosystem capacity to continue producing ecosystem services for local communities, allowing ecosystems to withstand the impacts of climate change and other stressors. The financial/economic aspect is also important to be evaluated. Therefore, actions should be supported by local, regional and national governments and involve synergistic interactions between multiple sectors considering social, institutional and political issues that can influence the implementation of EbA initiatives (IIED 2016).

This work proposes all these issues to be considered when evaluating, proposing and implementing EbA actions in the planning and operation of hydroelectricity generation, in addition to defining the objectives and goals to be achieved over time. In order to do so, we propose some examples of possible measures to be explored that can meet the mentioned criteria and are in accordance with the commitments established by Brazil in the NDC and with the NAP.

EbA and Sustainable Hydropower

In the previous section we mentioned the principles of the EbA. This paper suggests some possible actions, which should be complementary and synergistic, and can effectively contribute to the restoration, maintenance or enhancement of ecosystem capacity to produce environmental services that are essential to local communities, thus increasing their capacity to adapt to climate changes. In this way, the need for integrated vision in the definition of measures is reinforced. We also suggest some measures to be integrated on: a Biodiversity and Ecosystem Conservation Plan, a Plan to Support Sustainable Local Economic Activities, and a Plan to Promote Scientific Research. Other possibilities may be evaluated in each environmental study and according to each context.

Biodiversity and Ecosystem Conservation Plan

Three possible complementary actions aligned with the concept of EbA are suggested: financial support to protected areas; creation of new protected areas and improvement of existing protected areas, as described below.

Financial support to existing protected areas:

A contribution to the conservation of ecosystems is always guaranteed, since current Brazilian legal framework already requires the payment of environmental compensation when implementing new hydroelectric projects. An alternative action that fits the principles of the EbA is the additional support for protected areas, which may be in the form of financial resources.

The financial resources can be very important for the implementation and maintenance of protected areas, as there is often a need to remove people, or even for CAPEX investment, such as new vehicles or other equipment important to support monitoring activities. A good example of financial support program is the ARPA Program, "Protected Areas of the Amazon", created by the Brazilian Environment Ministry (MMA 2015), aiming the conservation and sustainable use of tropical forests.

Creation of new protected areas:

The participation of the company in the process of creating new protected areas is another interesting possibility. According to ICMBIO,[1] the legal process for the creation of protected areas in Brazil is a manifestation of interest of some sector of society (ICMBIO 2015). This is a great opportunity for the concessionaire to act within this process, such as suggesting the location of the new protected areas, which should be preferably in the vicinity of the plant or reservoir, joining the mosaic of protected areas in the vicinity. Another possibility is the creation of a protected area managed by the company, which is called in Brazil RPPN ("Reserva Particular do Patrimônio Natural or Private Natural Area", in Portuguese). The RPPN should cover the surroundings of the hydropower project, aiming to prevent the expansion of human occupation over the natural or forested areas, guaranteeing the ecosystem conservation and maintenance. The RPPNs can also act as buffer zones for existing non-private protection areas, creating a biodiversity conservation corridor.

Improvement of existing protected areas:

The entrepreneur may also consider the support for the improvement of existing protected areas under the Biodiversity and Ecosystem Conservation Plan, either through partnerships or even helping in the assessment of management effectiveness of a protected area. Regarding partnerships, we mention the ICMBio published in 2009 and the Manual of Procedures (ICMBIO 2009). Although the latter does not define a specific regulatory framework for shared management, it defines ways of establishing partnerships for the participation of other entities in management of protected areas.

There are some examples from the electricity sector and also from other sectors in Brazil where there was an effective participation of large structuring companies in the processes of creation and maintenance of protected areas that shows a great value for the conservation of the ecosystems (CEPEL 2016).

Another way of assisting in the improvement of protected areas is by establishing a continuous process of assessing the effectiveness of the management of protected environments, identifying strengths and weaknesses and planning for future actions. This applies to protected areas generally under the responsibility of the entrepreneur, such as the reservoir borders. Currently there is a methodological framework available for this purpose in the literature, with emphasis on the RAPPAM—Rapid Assessment and Prioritization of Protected Area Management method (Ervin 2003). Evaluation of management effectiveness is recognized worldwide as a vital component for obtaining a transparent, proactive and well-run conservation unit management. Besides being an essential tool for the local, regional and national level, this type of evaluation has gained a great deal of attention in the international context (Hockings et al. 2006).

[1]Acronym for Chico Mendes Institute for Biodiversity Conservation (Portuguese: Instituto Chico Mendes de Conservação da Biodiversidade). ICMBio is the Brazilian Ministry of the Environment's administrative arm.

Local Economic Activities Support Plan (LEASP)

The Local Economic Activities Support Plan (LEASP) must contain a spectrum of actions that is capable of promoting a better regional insertion of the hydroelectric projects in its areas of influence, promoting environmental conservation and sustainable economic activities. The participation of the stakeholders involved in this process is important for the success of the proposed initiatives, since they should develop autonomy to continue the activities promoted by the plan and its programs.

The composition of LEASP encompasses environmental programs that are currently used in the basic environmental plans of hydropower plants in Brazil. The novelty of this proposition is the focus on restoring, maintaining or increasing the capacity of ecosystems to produce environmental services that are essential to local communities.

Another area that may inspire the elaboration of plans, programs and projects aimed to promote sustainable local economic activities at local and regional level and environmental conservation are the national reports that show good practices in the management of protected areas. The publication of ICMBio/IPE (2014), is one of these reports, and contains some examples of practices, such as the ones highlighted below:

- Taim Ecological Station (Rio Grande, RS): The project focuses on the negotiation processes with local community to expand the protected area through the creation of an advisory council. The methodological basis was to qualify the participatory processes, identify and expose the different needs of the beneficiaries of environmental services, produce documents in a participatory way and give transparency and wide publicity to the process.
- Tefé National Forest, Extractive Reserve of the Jutai River, Extractive Reserve Baixo Juruá, Extractive Reserve do Juruá, Extractive Reserve of the Unini River, Marine Extractive Reserve do Soure: The project "Young Protagonists" seeks to diagnose and foster the emergence of new youth leaderships in federal protected areas. For this, it develops community strengthening actions and amplify the knowledge of the participants about conservation, biodiversity monitoring and environmental education.
- Trombetas River Biological Reserve (Oriximiná, PA): The Project "Participatory Monitoring of the Reproduction of Amazonian Chelonia" transformed a conflictive relationship between the managers of the protected area and the surrounding *quilombola* community, who came to be seen as an important player in the biodiversity conservation.
- Medium Purus Extractive Reserve (Lábrea, AM): ICMBio has built agreements with local communities to carry out sustainable fisheries management in the region. After five years an annual quota of expenditure was released and rules for the expenditure were established, followed-up by ICMBio. As a result, there was a decrease in illegal catch and marketing, which promoted community engagement and illegal catch control.

Plan to Promote Scientific Research

The System of Investments in Research and Development and Energy Efficiency by the concessionaire, permission and authorized companies of the electricity sector in Brazil, establishes a regular source of financial resources for the development of R&D projects, which originated from generation, transmission and distribution companies that operate regularly in Brazil (CGEE 2015).

The scientific presence and monitoring of biological, geological, ethnic, archaeological, social and cultural diversity through permanent research stations can provide scientific information and relevant analyses. Thus, the present proposal suggests the establishment of a Plan to Promote Scientific Research, consisting of a set of guidelines for all research activities from the implantation to the operation of the plant.

With the insertion of a major infrastructure project in a region with low anthropogenic occupation, opportunities for development and financing of research projects are opened, with emphasis on expanding the scientific knowledge base on the region in the physical-biotic or social aspects. What is proposed here is to go beyond the surveys required to carry studies for the environmental permits, establishing a continuous research program that can encompass different aspects, expanding scientific knowledge about biological, geological, ethnic, archaeological, social and cultural diversity of the region. This knowledge may be used as important inputs for the development of public policies focused on biodiversity conservation and maintenance.

Here we suggest some major themes that can be worked out within the framework of a Scientific Research Promotion Plan and which are directly related to the most evident research needs in sensitive areas that can be affected by possible climatic changes. Examples are: landscapes, ecosystems and species (population studies - monitoring, specific studies (e.g. ichthyofauna), ecology of target species, genetics and taxonomy, *latu* sensu landscape studies, ex situ conservation, reintroduction, geographic distribution); environmental pressures (conflicts with human practices, pollution, climate change); invasive alien species (impact of alien species); sustainable use of natural resources; and socio-biodiversity (conservation medicine, thematic maps, social and economic studies, ethno-cognition).

Conclusion

The present paper showed that it is possible to establish a set Ecosystem-based Adaptation measures (EbA) since the planning and project phase up to the operation of hydroelectric plants that aim to contribute to the conservation of biodiversity, to the generation of socioeconomic benefits to local communities and to construction and maintenance of the knowledge and practices of traditional local communities .

Table 3 Summary of proposed EbA measures for Sustainable Hydropower in Brazil

EbA measure	Ecosystem service	Benefits	Adaptive capacity needed	Exemples of indicators
Expansion of protected areas	R/P/S/C[a]	Direct	Medium	Area or % of protected area
Reforestation	R/P/S	Direct	Low	Area or % of reforested area
Restoration of ecosystems	R/P/S	Direct	Medium	Area or % of restored area
Conservation of forest remnants	R/P/S	Direct	Low	Area
Support for local sustainable economic activities	P	Indirect	Low	Number of plans supported Number of stakeholders involved Level of cooperation between govern-ment/companies/community
R&D	R/P/S/C	Indirect	Low	Number of studies Species and ecosystems benefited by the studies Communities benefiting from the results of the studies

[a]*R* Regulating Service; *P* Provisioning Service; *S* Supporting Service; *C* Cultural Service

In addition, by working to promote the sustainable use of nature and biodiversity, the development and implementation of EbA measures promotes coherence with several relevant international commitments, such as the Convention on Biological Diversity, the Convention on the Protection of World Heritage, Cultural and Natural Heritage, the Ramsar Convention on Wetlands, among others.

Table 3 resumes how some suggested measures may be viewed as EbA measures, highlighting the related ecosystem services benefited, the potential benefits (direct or indirect), the adaptive capacity needed and some examples of indicator for EbA efficiency/effectiveness assessment.

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The Yellowstone to Yukon Conservation Initiative as an Adaptive Response to Climate Change

Charles C. Chester and Jodi A. Hilty

Abstract The need for connectivity across large areas has long been a core principle in the field of conservation biology. Whereas early rationales for conserving connectivity included the maintenance of genetic health and the protection of ecosystem processes, the more recently recognized threat posed by climate change to biodiversity has only amplified the focus on connectivity. Within the last decade, the term "large landscape conservation" has become a generic term applied to efforts intended to align on-the-ground conservation programs with the scale of the potential changes resulting from climate change. An early example of such an approach was the Yellowstone to Yukon Conservation Initiative (Y2Y), spanning the Rocky Mountains between Canada and the United States. First conceived in the early 1990s, Y2Y connoted not only a region, but also a science & advocacy network, a conservation organization, and—particularly in its early years—a challenge to the conservation community to broaden its vision of what will be required for effective wildlife conservation over the coming century. This includes consideration of how, under conditions of climate change, biological communities may disarticulate and then reorganize across time and space, and of the consequent need for intact land conservation networks to allow species to move through increasingly human-occupied landscapes. Accordingly, a key aspect of the programmatic work under Y2Y focuses on protecting ecologically intact landscapes as a core approach to effective biodiversity conservation. Today, Y2Y has become widely cited for its groundbreaking efforts to expand the conceptual scale of effective conservation landscapes in North America and the world.

C. C. Chester (✉)
The Fletcher School, Brandeis University, Tufts University, 9 Lowell Street, Cambridge, MA 02138, UK
e-mail: charles.chester@tufts.edu

J. A. Hilty
Yellowstone to Yukon Conservation Initiative, Suite 200, 1240 Railway Avenue, Canmore AB T1W 1P4, Alberta, Canada
e-mail: jodi@y2y.net

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Introduction: Science and Conservation in the Y2Y Region

Although biodiversity is responding to climate change in myriad ways, range movement across landscapes (and seascapes) is perhaps the most widely recognized. In particular, species movement both latitudinally (e.g., poleward) and/or altitudinally (e.g., upslope) has been documented in numerous cases, although the overall patterns of species movement are complex and do not indicate a simplistic species response mechanism (see Lenoir and Svenning 2015; Pecl et al. 2017). Nonetheless, at local, national, regional and global levels, many actors in the conservation community have responded to the threat of climate change by focusing on "large landscape conservation," a generic term applied to those efforts intended to align on-the-ground conservation programs with the scale of these documented and projected movements.

The Yellowstone to Yukon (Y2Y) region has been widely profiled and recognized as one of the world's first large landscape conservation efforts—sometimes called "continental scale" conservation efforts (Johnson 2017). Much of the programmatic work currently conducted under the Y2Y aegis focuses on the need for ecological connectivity across large landscapes, with the ultimate goal being to enhance the resilience of wildlife to the threat of climate change. Yet to garner a full understanding of Y2Y's current approach to grappling with the threat of climate change, it is useful to begin with a short review of Y2Y's early history.

Within two years of its first conception in 1993 (Locke 1993/94), Y2Y had evolved into a highly active "virtual network" of biologists and conservationists who were interested in the idea. Over the following half-decade, an organization with the formal title *Y2Y Conservation Initiative* solidified with the mission of both promoting a larger landscape vision across the broad region and of prioritizing conservation resources toward areas of critical conservation concern (Chester 2006). Overall, the idea of "Yellowstone to Yukon" has since manifested itself in at least four principal ways:

- Y2Y is a *region* stretching 3218 km across one of the planet's most intact mountain systems, from the Arctic Circle in the Yukon south to Greater Yellowstone Ecosystem's Wind River Range, encompassing five US states, two Canadian provinces, and two Canadian Territories.
- Y2Y is a *network* of hundreds of individuals, conservation organizations, businesses, and other actors both within and outside the region.
- Y2Y is an *organization* based in Canmore, Alberta, which conducts a range of conservation activities throughout the region.
- Y2Y is a conservation *vision* of a continental scale, one of the first of its kind.

Over the subsequent twenty-plus years since its original conception, Y2Y has become commonly cited as one of world's most ambitious examples of large landscape conservation; as one observer described, Y2Y has become "perhaps the granddaddy of citizen-generated large-landscape projects" (Hiss 2015).

Today, one can see the same suite of large mammals in the Rocky Mountains that Alexander MacKenzie saw in 1793, when he became the first Caucasian to cross the continent north of Mexico (Gailus 2010). However, many of these species, including wolves (*Canis lupus*), grizzly bears (*Ursus arctos),* wolverines (*Gulo gulo)*, and caribou (*Rangifer tarandus*) have become imperiled, particularly in the southern portion of the Y2Y region. Approximately 700 protected areas in the Y2Y region—which includes the world's first national park (Yellowstone), Canada's first national park (Banff), and the world's first international peace park (Waterton-Glacier)—are the core mainstays of biodiversity conservation for the area (Chester 2015; Chester et al. 2013).

Scientific understanding has been at the core of the Y2Y vision since its conception. Both the theory of island biogeography and metapopulation theory served as key rationales, both of which indicated that the survival of individual species and maintenance of overall biodiversity would be enhanced by larger protected areas that were situated both closer together and within a permeable matrix (Hilty et al. 2006). Although the Y2Y region has a comparatively high percentage of its land base in protected areas, on their own they will not adequately protect biodiversity partially because they do not extend over the region's full breadth of natural habitats, and partially because their extent is sufficient to maintain either lasting populations of wide-ranging species nor the natural processes they depend upon (Hilty et al. 2006).

Methodology and Limitations

Our primary purpose here is to explain the role of Y2Y in activities pertaining to biodiversity conservation in the Northern Rockies of Canada and the United States, with a particular focus on both (1) the effects of climate change on biodiversity and (2) the conservation responses to the threat of climate change. Both authors have been involved in Y2Y for a combined thirty-plus years as academic researchers and as board members and/or staff. In addition to our own experience with and involvement with Y2Y, we have cited a range of sources from the academic literature—mostly journal articles and academic books, but also reports from the conservation community (mostly NGOs) and media/press coverage. While our background with Y2Y enhances our historical insights and we have attempted to examine Y2Y objectively, this association requires up-front recognition. Another important potential limitation includes the fact that we do not closely examine several other early efforts at large landscape conservation, such as those that occurred in Central America, regions of eastern United States (such as New York and Florida), and other areas (see Worboys et al. 2010), and our focus on Y2Y should not be interpreted as a claim that Y2Y was alone in early efforts to foster large landscape conservation.

Y2Y as a Response to Climate Change

Scientific reviews from on climate change and biodiversity repeatedly recommend and prioritize (1) increasing the number and size of protected areas and (2) working to functionally connect protected areas as the key actions that society should take to conserve biodiversity into the future (Heller and Zavaleta 2009; nearly a decade after this groundbreaking review, there remains active discussion over the role of connectivity in biodiversity conservation; see, for instance, Bonebrake et al. 2018; Reside et al. 2018; Jones et al. 2016; Sirami et al. 2017; McGuire et al. 2016). Such recommendations are essentially congruent with the Y2Y mission of connecting and protecting the habitats across the Y2Y region. Progress with regards to such goals has been made; in the first 20 years since the operationalization of the Y2Y vision, the area under strict protection (e.g., legislated parks, wilderness, and other designations) increased from 9 to 14% of the region (Wendy et al. submitted). Still, parts of Y2Y are disconnected for some species, and increasing human activities continue to threaten to isolate protected areas currently connected.

A wide range of sectors are highly active in the conservation arena in the Y2Y region, including government agencies, industry, indigenous communities, and non-governmental organizations (NGOs). The latter includes traditional conservation and environmental groups employing advocacy and litigation, as well as sportsmen and angler organizations, land trusts, scientific institutions, local community groups and watershed associations. Notably, Y2Y the organization (more below) has supported scientific work in the region to identify and draw attention to place-based and issue-based conservation priorities, and has worked to bridge efforts amongst partners working to further scientific understanding of the region.

In the context of this conservation-rich and science-rich history, a vast array of government, academic, and independent scientists have conducted a myriad number of biological, social, economic, and political conservation-relevant investigations in the Y2Y region, with the result that the Y2Y region is probably one of the better-studied regions of the world when it comes to the practice of conservation. Partly because the region has been imbued with these conservation values and biological insights, the conservation community has been relatively quick to focus on the challenge of climate change. That said, much remains to be done, and preparing for climate change will need to occur at multiple scales from the very local to pan-regional.

Overall, as climate change confronts the historical legacy of conservation in the Y2Y region, the conservation community holds itself to a two-fold proposition: first, that a 150 year-old experiment in protecting wildlife and wildlands will continue to benefit future generations, and second, that in this era of climate disruption, on-the-ground conservation from the local scale to the continental scale will foster effective resilience and adaptation.

Range of Anthropogenic Threats to Biodiversity

Human population density in the Y2Y region is relatively low. Natural resources, be it land, wildlife, minerals, or oil and gas, are managed through a complex web of federal, provincial, state, and local agencies. Natural resource extractive industries in the region include mining, and oil and gas extraction, forestry, agriculture, ranching, and grazing. While these activities still dominate in many parts of the region, the economy has increasingly shifted toward "nonconsumptive" industries such as outdoor recreation, tourism, a wide range of service sector businesses, and amenity migration, which as been defined as "population movement towards natural amenity-rich rural communities, a phenomenon that has been prominent in many parts of the world in the last four decades" (Matarrita-Cascante 2017). While there are prima facie reasons to interpret these developments as beneficial for conservation, two key points must be taken into account. First, the term "nonconsumptive" may be a misnomer; for example, the impacts of tourism—even "ecotourism"—can be significant (see, e.g., Blumstein et al. 2017). Second, although these changes have led to a diversifying political landscape, the region's politics remain largely favorable toward the extractive industries.

While biodiversity across the Y2Y region is threatened by a familiar list of human activities, the degree and types of threats change from south to north. Southward, rural residential sprawl constitutes the most significant factor in land-use change and the resultant threats to wildlife species (Hamilton et al. 2016; Farr et al. 2017). For grizzly bears, a single house per square mile can mean the difference between good habitat and sink habitat—that is, where conflict with humans typically means the demise of bears (Schwartz et al. 2012). As one moves north through the region, areas with little permanent human presence are increasingly facing new or expanded forms of natural resource extraction—including unsustainable forestry practices, oil and gas development, mineral exploration, as well as the placement and extent of renewable energy projects and infrastructure. On top of this lies the threat of climate change.

To protect the region's biodiversity, conservationists have relied on a wide range of tools, including advocacy for enhanced protected areas, private land conservation, wildlife restoration initiatives, incentive programs, and education and conflict-reduction programs. In regard to targeting key public and private lands, approximately 14% of the Y2Y region lies protected under a range of designations, including wilderness areas, wildlife refuges, and national, state, and provincial parks (Francis et al. Submitted for publication). Extensive work on connectivity and road ecology has focused on mitigating the impacts of roads and highways, with particular focus on key transportation corridors such as the Trans-Canada Highway (which bisects Banff National Park) and Highway 3 (which runs through the Crowsnest Pass area of southern Alberta) (Paul et al. 2014; Sawaya et al. 2014). Significantly, the "Path of the Pronghorn," the first federally designated migration corridor in the United States, lies in the Y2Y region (Berger and Cain 2014; Degen 2014).

At each of these scales, connectivity work furthers the larger vision of the Y2Y region working as an enormous corridor made up of protected core areas and corridor linkages—which collectively ensure the long-term viability of the region's biodiversity.

Climate Change Impacts

Climate change can be seen as an external driver spread over the above "traditional" threats to biodiversity—one that will manifest itself differently across the Y2Y region, but overall will entail "profound effects" (Guay et al. 2016; although focused on the US portion of the region, this publication provides a thorough review of the effects of climate change for this area).

The Y2Y region is home to several research initiatives on the effects of climate change, with focal points ranging from niche habitats of particular species to extensive large landscape analyses. While the status of US government supported research initiatives remains uncertain, a few prominent examples of such research initiatives has included the Pacific Climate Impacts Consortium, the US Forest Service Rocky Mountain Research Station, the US Geological Survey's Northwest and North Central Climate Science Centers, the Northern Rockies Adaptation Partnership, and the Department of the Interior's Great Northern Landscape Conservation Cooperative.[1] While these efforts indicate that scientists and government officials have committed to research and understanding the impacts of climate change across the Rocky Mountains and adjacent ecoregions, continuing support for such research remains unclear for the US as of publication.

The potential for rapid climate change in the Rocky Mountains has been long recognized (Luckman and Kavanagh 2000). Mountain ecosystems are both being impacted by climate change at a faster rate than most other places (Pepin et al. 2015), and Y2Y is no exception with rates exceeding the global averages (Graumlich and Francis 2010). At the same time, Y2Y and other intact mountain ecosystems are highly likely to contain refugia for species during climate change since mountainous regions offer different aspects, elevations, and north-south movement options over relatively short distances (Chen et al. 2011).

A sizeable and expanding body of scientific evidence has shown that not only is the Y2Y region currently experiencing climate change impacts, but that continued changes will impose significant alterations to the region's ecology (Reiners et al. 2003) as well as agriculture (Hannah et al. 2013). Compared with the historical records, the region's mean annual temperatures have been increasing, precipitation patterns have changed, and there has been an increased frequency of extreme weather—the last of which could have the highest impact due extreme temperatures leading to stress, reproductive failure, and even death for the many species with relatively narrow climate envelop requirements (Graumlich and Francis 2010).

[1] Weblinks to these institutions can be found at http://ieinfo.net/geo-na-y2y.html.

Compared to previous decades, winters have been shorter and warmer in the twenty-first century. Precipitation is increasingly falling as rain instead of snow, which entails significant impacts on seasonal water availability as well as glaciers. One notable consequence has been the climate threat to Glacier National Park, where the park's namesake features are at risk (Luce 2018). Moreover, some species such as the wolverine (*Gulo gulo*) that may depend on permanent ice and snow throughout the year (typically for food caches and insulation) will experience the greatest impacts—although how this will unfold is highly complex, particularly in comparison to other anthropogenic threats aside from climate change (McKelvey and Buotte 2018; Stewart et al. 2016). Beyond such direct physical changes, species are experiencing phenological alterations, including shifts in species distributions, changes in hibernation patterns, and the potential decoupling of phenological timing between codependent species (Graumlich and Francis 2010). In some cases, climate change could entail benefits such as reduced cold stress and longer foraging seasons, yet the extent of such benefits is not clear. An illuminating case study can be found with marmot species (*Marmota* spp.) in the Rocky Mountains; on the one hand, while they may benefit from increased capacity to colonize new territory and increase populations, a drier and warmer active season may entail significant negative impacts (Armitage 2017; Turnock et al. 2017). Overall, the available observational data and modeling data point to (1) the changing species distributions in the Y2Y region, and (2) the likelihood of further change over the current century. As a consequence, species that are unable either to adapt or to relocate to areas with conducive climate and habitat conditions are unlikely to survive (Graumlich and Francis 2010).

Widespread outbreaks of pine beetles (most significantly, the mountain pine beetle, *Dendroctonus ponderosae*) have given the Y2Y region its most visible climate impact, with expanding stands of dying and dead trees now ubiquitous in much of the Y2Y region. Although a native species that has incurred extensive past infestations, recent infestations have been widely characterized as unprecedented, especially in regard to the beetles' effects on higher elevation, five-needle pine species, such as whitebark pine (*Pinus albicaulis*). These extensive infestations largely result from milder winters and the pine beetle's resultant capacity to shorten its life cycle (Loehman et al. 2018).

Discussion: Opportunities and Challenges

For conservationists working in the Y2Y region, climate change is not a newly-recognized threat (see, e.g., Luckman 1990). And when the concept of "Y2Y" was first proposed in the mid-1990s, the threat of climate change was one factor considered in the rationale for conservation at a large landscape scale (Harvey 1998). Yet the broad focus of conservation science at the time was on the increasing islandization effects of increasing natural resource extraction activities and the development of human infrastructure (e.g., roads & buildings).

Although the conservation community has by no means eliminated any of these long-standing threats, over the course of the last decade it has widened its focus to encompass the threat of climate change. Accordingly, climate science is advancing across the region, and to some degree has become a central focus for conservation activities in the region (Hilty et al. 2017). Climate change science both helps to inform how and whether conservation efforts to date will fare in terms of climate change and helps identify refugia. In the Columbia Headwaters region, for instance, Y2Y is working with the organization Wildsight and other partners on an expanded conservation vision based on science indicating that this area is likely to continue to serve as a climate refuge to a greater degree than other areas in the region (Utzig 2015). Such climate refugia will promote persistence for some species (McLaughlin et al. 2017) and can reduce rates of change and related extremes. Climate refugia such as in the Columbia Headwaters can exist for a variety of reasons, from weather patterns to topographic influences and vegetation attributes (Ashcroft 2010; Maclean et al. 2017).

While river systems have long been known to be vital to biodiversity in the Y2Y region and new research continues to expand on the importance of river systems (Hauer et al. 2016), Y2Y and partners are increasingly focusing on headwaters conservation both because water conservation is a major 21st Century climate exacerbated issue and because the issue resonates with people. One example of such a conservation push is in the Bighorn, an area lying mostly along the eastern notch between Banff and Jasper National Parks. More than 88% of the water for the city of Edmonton originates in the Bighorn, and recent polls show that residents in Edmonton are keen to conserve their headwaters (Hilty et al. 2017; Y2YCI 2016).

Another common recommendation of scientists for helping biodiversity during this time of climate change is restoration of impaired systems. The Kootenai Valley in north Idaho along the US-Canada border has suffered decades of major land use change, transforming this forested lowland ecosystem into a managed landscape of agriculture, cattle grazing, and dysfunctional hydrology that compromises this ecosystem's ability to adapt to the hotter, drier climate conditions forecasted for this region. Grizzly bear scientists mapped out large landscape connectivity priorities from the perspective of grizzly bears (Kendall et al. 2016; Proctor et al. 2015). To date, Y2Y has worked with land trusts in the region to purchase key connectivity lands, and currently Y2Y is engaging with the Idaho Department of Fish and Game to restore ecological functioning to 250 acres of forested lowland in the Boundary-Smith Creek Wildlife Management Area in the Kootenai Valley for the purpose of increasing the resiliency of this ecosystem to climate change. In this area, which is considered an essential corridor in the context of large landscape conservation, restoration efforts will include the construction of two ephemeral ponds for native amphibians, the planting of 50,000 native trees and plants, the restoration of ephemeral flood cycles to 1 mile of dry streambed, and the restoration of 35 acres to forested pollinator habitat. These restoration efforts are designed to increase this ecosystem's resiliency to climate change by restoring hydrological functioning to a portion of this watershed and by using topographical alterations to maximize cool air refugia; these efforts will also enhance connectivity for large mammals and local wildlife including pale jumping slugs and western toads, both listed as Species of Greatest Conservation Need in Idaho (IDFG 2017; Lucid et al. 2016).

Increasingly, conservation efforts across Y2Y are incorporating climate change considerations into prioritization and actions; at the same time, conservation responses to climate change—be it by government agencies, conservation NGOs, private sector entities, communities, or other actors—have varied widely across the region. Some have emphasized continuing with traditional land conservation efforts, such as local land trusts—although here there are a growing number of cases where the impact of climate change on water dynamics are being considered at a more local level. Other conservationists have responded to the threat of climate change by making the case that, in essence, their long-standing conservation priorities already *are* a response to climate change—at least to the degree that their traditional focus on maintaining connectivity, protecting core areas, and eliminating threats such as invasive species are also the priorities that will enhance resilience and the capacity to adapt to climate change (see Butt et al. 2016). And others are engaging with new approaches and tools, ranging from incorporating the impacts of climate change into formal analyses (Weaver 2011, 2017) to targeted beaver (*Castor canadensis*) restoration efforts to help raise ground water levels, cool in-stream water, and extend mountain water run-off periods (Gibson and Olden 2014).

But even as climate change considerations are being incorporated at the planning level in the Y2Y region, the reality is that many institutions are still working to account for climate change in their working agendas; moreover, a relatively new US federal agenda intends to gut climate change preparedness initiatives. Yet perhaps more fundamental challenge for the conservation community is the degree to which many citizens living in the Y2Y region reject the premise of anthropogenic climate change. Despite overwhelming scientific evidence, this backlash influences particular sectors in the Y2Y region and presents significant challenges in incorporating climate change considerations into policy and management decisions. Without addressing this problem directly, the conservation community in the Y2Y region will continue to face institutional resistance to incorporating climate change into natural resource management.

It is important to point out that efforts to reduce greenhouse gas emissions through renewable energy can, under some conditions, entail roughly equivalent impacts as carbon extraction in terms of footprint on biodiversity and habitats. For example, growing wind and hydro power generation projects are increasing their collective footprint in the Y2Y region. As they expand, they could conflict with a number of specific conservation priorities unless carefully placed.

Another central challenge to the conservation community may be its own history, which since the 1872 establishment of Yellowstone National Park has been one of parceling out specific areas on the assumption that stasis in land use (i.e., land preservation) is equivalent to inherent conservation value. This approach assumed that if a sufficient portion of land were to be designated as “protected areas,” they could effectively conserve a region’s biodiversity. Although protected areas remain key to conservation, their role is shifting; the threat of climate change now requires conservationists to work across much larger landscapes, not only to ensure their capacity to move across those landscapes, but to preserve ecosystem functions. Generally speaking, both a precedent and a mechanism for effective and coordinated multijurisdictional planning and implementation remain lacking.

Ultimately, conservationists in the Y2Y region—as with conservationists around the globe—are beginning to incorporate and prioritization adaptation to climate change in various efforts. Still, these efforts will not be successful unless the world steps up efforts on the mitigation side of the climate equation. Also, while most people working to address large landscape conservation in the Y2Y region understand that the adaptation means ensuring that ecological changes sustain changing configurations of biodiversity, climate science and supporting information is still lacking to guide clear decisions in all cases. This means that some partners are hesitant to incorporate climate change considerations or to adapt what they are doing to better support climate resilience. In the Y2Y region, both because of the rapidly expanding human footprint and the increasing evidence of climate change-related impacts, it is clear that time is limited and, consequently, that the more actors across the region step-up to consider climate change, the likelier that the region's biodiversity will persist into the future.

Although we do not know exactly how climate change will affect the Y2Y region over the coming decades, we do know enough to expect that the region will see significant and unpredictable ecosystem changes due to alterations in temperature and precipitation. Consequently, if it is to remain relevant and effective, the conservation community has not choice but to forswear the assumption that a traditional conservation model will sufficiently protect the region's biodiversity. At a global level, as hydrodynamic flows are altered by climate change, ensuring the region's freshwater supplies to its full range of users is likely to become one of the most contentious resource challenges facing humankind. In the Y2Y region, changes in precipitation form (viz., rain or snow) and quantity is likely to result in certain seasons becoming more arid, with resultant higher demands during certain times of year from agricultural and municipal users. This in turn is likely to lead to pressure for more dams—even as climate change makes survival challenging for aquatic species that dependent on free-flowing and cool streams. If such conflicts are not prioritized and addressed proactively, it is unlikely that these vulnerable species will be protected under conditions of unmanaged resource scarcity. Similarly, ensuring connectivity for wide-ranging and migratory species will be critical, and thus understanding which kinds of corridors or linkages will remain robust over long-term conditions of climate change will be essential (Cross et al. 2012).

Another promising approach is to identify and protect regions of "climate refugia," or areas where glaciation did not occur (Dobrowski and Parks 2016; Graumlich and Francis 2010). Although the location of past refugias hold no necessary promise for warmer future, the multifaceted mountainous terrain of the Y2Y region may well ensure conditions that protect species from current and impending changes.

Conclusion

Over the past century, portions of the Y2Y region have been the subject of extensive and intensive scientific attention. As a result, there is a substantial body of scientific knowledge and insight to undergird biodiversity conservation as the region becomes increasingly subject to conditions of climate change. Despite this knowledge, however, considerable uncertainty remains both for the region as a whole and for any particular subregion of the landscape. With such uncertainties in mind, the conservation community must ensure that across the Y2Y region as a whole, plants and animals can move and shift into appropriate habitats and niches according to local and subregional patterns of a changing climate. As one of us helped to articulate in a defense of US system of Large Landscape Cooperatives (LLCs; see Baldwin et al. 2018), Y2Y's response to climate change must incorporate the following objectives:

1. maintain and expand placement of core conservation areas;
2. build network connectivity responsive to the changing climate;
3. assess habitat vulnerability to potential land-use change;
4. integrate social constraints with biodiversity and ecosystem-service goals, and
5. compare alternative scenarios.

When Y2Y was first conceived in 1993, conservation biologists were primarily concerned with decreasing genetic connectivity due to anthropogenic landscape change. As climate change became more widely recognized in the conservation community, the need for effective connectivity as a tool for responding to climate change became a driving rationale in efforts to conserve habitat. Accordingly, over the course of the past decade, working at a "large landscape scale" has become *de rigueur* in the arena of conservation biology and conservation implementation.

In such a world of accelerated climate change, the Y2Y region presents one of the world's most significant opportunities to work at a large landscape scale. The ecological integrity of the Y2Y region derives from a number of factors: the region is comparatively intact and untrammeled, it contains a wide latitudinal range, and its mountainous terrain incorporates both elevational gradients and diverse north-east-south-west aspects (Pecl et al. 2017). Together, this means that the Y2Y region will carry more resilience to climate change than many other regions. Given the opportunity presented by the Y2Y region's high level of resilience, it remains critical to devise and implement "climate-effective" conservation actions today so that the region's species will remain viable under conditions of dramatic change.

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Saving the Last Endemic-Church Forests in Ethiopia: The Case of Lake Tana Biosphere Reserve

Teowdroes Kassahun and Svane Bender

Abstract The restoration of degraded forests to maintain ecosystem services, conserve endemic biodiversity and to enhance climate change adaptation is a major concern in developing countries. In Northern Ethiopia, large forests have been converted into arable land; today the last remaining refugia for native woody plant species are found around churches. The so-called church forests are considered as the last natural seed banks for native trees species, reference areas for local endemism and last corner stones for species distribution. Against this background, NABU, a German originated NGO, initiated a conservation programme and investigated the species and structural composition of 10 pilot church forests. A total of 74 woody species (41 tree, 26 shrub and 6 liana species) representing 32 families were recorded. Differences between forests were strongly expressed in species number (14–35) and number of seedlings (150–4150/ha). Similarities between forests decreased following the altitude difference. It was found that for successful restoration of the pilot forests, interconnecting them by vegetation corridors, creating buffering areas and livestock fencing as well as and reforesting were suitable measures. NABU therefore implemented a restoration programme for safeguarding the last green forest islands together with the Ethiopian Orthodox Church.

T. Kassahun (✉)
Department of Ecology, Faculty of Environmental Sciences, Czech University of Life Sciences, Kamýcká 129, 165 21 Prague 6—Suchdol, Czech Republic
e-mail: Teka@fzp.czu.cz

S. Bender
The Nature and Biodiversity Conservation Union (NABU), Charitéstr. 3, 10117 Berlin, Germany
e-mail: Svane.Bender@NABU.de

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Introduction

Climate change is one of the most serious environmental, social and economic threats affecting millions of people worldwide. Its impact is much more visible in developing countries by deepening poverty, food insecurity, poor livelihoods and unsustainable development (FAO 2005; IPCC 2007). This level of vulnerability is largely because of the population's high dependence on ecosystem services and limited capacity to adapt to a changing climate (MEA 2005). Hence, adapting to these changing conditions is becoming a necessity in order to decrease their impact on human wellbeing. In this context, forests conservation must be considered as one of the major options for adaptation to a changing climate. This is largely because a significant part of the population relies on forests as safety nets during harsh periods (Nkem et al. 2007). In Ethiopia, land degradation and deforestation are impairing the capacity of forests and the land to contribute to food security. The country is facing a population growth rate of at least 2.9% (Anteneh 2017) which is one of the highest in the world and results in extensive forest use and clearing for farmland, fuel wood, fodder and construction materials. Furthermore, a constant fragmentation of forests into small patches is influencing the forest structure and species composition and ultimately leading to habitat loss (Echeverria et al. 2006). The fragmentation and isolation of forests in Northern Ethiopia Highlands, at Lake Tana Biosphere Reserve, represents a particular case.

At Lake Tana Biosphere Reserve region, forest cover has decreased from 40% to less than 1% within the last 50 years. Most of the forest residuals, mainly small patches are now located at churches and monasteries (zur Heide 2012). These so-called church forests are integral part of the Ethiopian Orthodox Tewahido Church (EOTC), which originate in the fourth century AD (Wassie 2002). Almost all EOTC, are surrounded by a ring of forests and remained in the landscape, even though large-scaled deforestation has occurred in the Ethiopian Highlands. These "church forests" provide sites for religious ceremonies, social gatherings and burial grounds. Most of these forests, though poor in regards to species abundance and biodiversity today; are dominated by natural, indigenous tree species. Many forests host endemic and endangered species that are extinguished in other places. They can be considered as important reserves for species and biodiversity conservation and buffer against depletion. Church forests are also an important seed source for rehabilitation for degraded areas. Overall, church are considered as forests serving as in situ conservation sites for biodiversity, in particular for indigenous trees and shrubs, which escaped from being destroyed forever under the shelters of the church value (Wassie 2002). Deforestation threatens the long-term water supply of the local population. There are also rises in ground-surface temperature, altered precipitation patterns and more frequent droughts induced by global climate change, which amongst other things, has a negative impact on agricultural yields. Some case studies of Ethiopia and other sub-Saharan countries (partly considered in the IPCC 4th state of play report) have modelled the interaction of climate change, changes in land use, deforestation and surface run-off, as well as groundwater recharge in catchment areas.

It became apparent that rising temperatures increases evapotranspiration and in so doing reduces groundwater recharge, whilst the increase in heavy rainfalls markedly increases surface run-off and groundwater recharge. In combination with deforestation and the degradation of pasture and agricultural areas, which also increase surface run-off, these factors further advance soil erosion, and lead to flooding and reduced water quality downstream. The latter will have a serious impact on Lake Tana itself.

Although church forests have been considered as stable for several decades, they are now visibly affected by encroachment from adjacent farms, unlawful livestock grazing within the church compound, illegal harvest of forest products (Woods et al. 2017), and extensive expansion of non-indigenous tree like *Eucalyptus* spp. (Liang et al. 2016). Additionally, these forests are residuals from previously well-established and connected forests, but now exist as isolated forest fragments in the landscape. Fragmented forests are generally more susceptible to degradation compared to large intact forests due to edge effect that creates artificial boundary (Laurence et al. 2011). They are also much more exposed to higher wind, higher temperature and lower humidity at the edge compared to the interior of the forest (Laurence et al. 1998) resulting to mortality of seedlings (Zambrano et al. 2014). This all affects the long-term existence of these small forests.

Against this background, NABU, a German originating NGO, initiated a church forest, conservation programme in 2013. NABU supported technically and financially the establishment of Lake Tana Biosphere Reserve as a wider approach for conserving habitats, culture and biodiversity, while opening up sustainable development opportunities like ecotourism or regionally produced and labelled products for local communities. NABU works towards conservation and sustainable development in Ethiopia since 2006 having a specialisation on UNESCO biosphere reserves' establishment and management. After securing the legal protection of parts of the area as core zones of the UNESCO biosphere reserve, it seemed of major significance to maintain the last forest islands of the former forested area. According to NABU, ecological restoration efforts should both focus on maintaining forest species diversity and ecosystem services of the last remaining forests by creating conditions that facilitate regeneration of the various species within the forest as well as expanding forest area, interconnecting patches and creating new ones. In order to understand forest structure, ecology, threats and socioeconomic pressures, a baseline study on species and structural composition as well as the living conditions of adjacent communities, was therefore assigned by NABU to the Amhara Regional Agricultural Research Institute (ARARI). Based on the study, detailed and participatory elaborated forest management plans for restoration and interconnection for each forest as well as income generation schemes for the local communities living around the church forests were planned to be developed. In the course of an extended field survey on present church forests in the wider area, ten pilot church forests at Lake Tana Biosphere Reserve were selected and assessed in detail. This paper presents the ecological main results of the study addressing the following questions: (1) What is the forest structure and species composition of the 10 church forests? (2) Which possible measures could be taken for conservation and restoration of the church forests in order to preserve biodiversity and contribute to adaptation to climate change?

The findings of the study and NABU's approach for conserving some of the last forest patches and their biological diversity might add to the little existent knowledge on forest churches in the Lake Tana Basin and support the biosphere reserve management unit, local administrations and other stakeholders in their efforts to maintain the last indigenous forest resources of Lake Tana area.

Materials and Methods

Study Area

The study was conducted in north-eastern Ethiopia, at Lake Tana Biosphere Reserve (see Fig. 1). The Lake Tana Biosphere Reserve is located in the Amhara National Regional State approximately 563 km northwest of Addis Ababa in the north-western part of Ethiopia. The biosphere reserve comprises Lake Tana, the largest lake in Ethiopia, the main source of the Blue Nile, which provides important ecosystem services. The area is a hotspot of biodiversity, internationally known as an Important Bird Area and is of global importance for agricultural genetic diversity. The area is characterized by an enormous heterogeneity of land uses and natural ecosystems. Amongst the 10 administrative districts (locally known as Woredas) that are encompassing the Tana Lake, the Dera district has been chosen for both the study and the piloting of selected measures. Dera is located at the eastern part of the lake covering an estimated area of 149,726 ha, at an altitude ranging between 1500–3200 m.a.s.l. The rainfall is characterized by a bimodal distribution with the main rainy season from June to August and a small rainy season from March to May. The average rainfall varies between 1000 and 1500 mm and the annual average temperature ranges between 13 and 27 °C (BoA 2013). The topography comprises uneven and ragged mountainous highlands, extensive plains and few deep gorges. The area is part of the most degraded and eroded parts of the regional state of Amhara. The common soil types are nitosol and vertisol. The dominant land use system is farming covering almost 46% of the district followed by small forest patches, in which almost 50% of it belonging to the so-called church forests. The district has a total population of 259, 113 of which 98% are members of the EOTC (CSA 2007).

Out of 1404 church forests in that administrative zone (South Gondar administrative zone), 10 church forests were selected for the study. The selection criteria focused on forests being bigger than 1 ha and of comparable altitude, with the exception of Abune Aregawi church forest (0.7 ha) which was included as it is located in a strategic location and useful as a stepping stone to link other forests ecologically. All studied forests are located in so called the buffer zones of the Lake Tana Biosphere Reserve and cover a total area of 89.3 ha (Table 1).

The church forests sizes varied between 0.7 and 44.2 ha; most churches were established between 368 and 1984 A.D (Wassie et al. 2010). Out of the 10 selected church forests, only 5 served for pilot measures and monitoring.

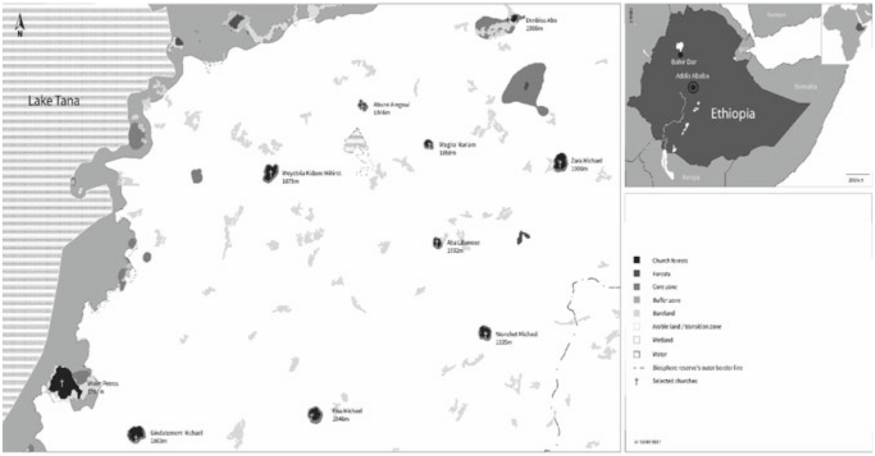

Fig. 1 Location of the study area in the South Gondar Administrative Zone, at Lake Tana Biosphere Reserve, Ethiopia (NABU 2017)

Table 1 Characteristics of the 10 pilot church forests selected for the study

Name of church and forest	Altitude (m)	Forest area (ha)	No. of plots*
Abune Aregawi	1846	0.7	2
Denbiso Abo	1906	1.85	4
Wagira Mariam	1888	2.5	8
Aba Libanos	1932	2.8	11
Wonchet Michail	1935	6.2	12
Fisa Michail	1846	6.9	16
Woyebila k/miheret	1878	7.43	22
Zara Michail	1906	8.3	21
Gindatemem	1863	8.4	27
Wolet Ppetros	1797	44.2	20

*Each plot measures 10 m × 10 m

Data Collection

In all 10 forests, a randomly oriented transect line was laid out with 10 m × 10 m plots located at a distance of 50 m along transects. Other transects were then laid out parallel to this first transect, at 50 m distance from each other. For the largest forest, Wolete Petros, 44.2 ha, transects and sample plots laid at 100 m intervals. Consequently, 2–27 plots were established in each forest depending on their size leading to 148 sampling plots. For each church forest, the forest borders were mapped and the areas covered by trees within the boundaries were calculated (Fig. 2). The areas occupied by church buildings as well as other non-forested sites were measured and subtracted from the

Fig. 2 Aerial photograph of a typical church forest surrounded by arable land at Lake Tana Biosphere Reserve (*Photo* Prof. Michael Succow)

total area to reach the actual forest area. The altitude of the forests was determined at the central location within the forest. In each sample plot, tree and shrub species, were identified and counted to estimate the number of individuals per species. Diameter at 1.3 m height was measured for each tree in the sample plots having >5 cm diameter and >1.3 m height and the number of saplings with <1 cm diameter and <1.3 m height was recorded in each sample plot. Seedlings were counted in a 5 m × 5 m sub-plots within each of the main 10 m × 10 m plots. Plants with multiple stems at or below 1.3 m height were treated as a single individual. The heights of all woody species were measured using a hypsometer and meter tape. Leaf litter depth was measured from the litter surface to bare organic soil at 4 points, one at the centre, at two corners and one in the middle of one side of each plot. The number of clearly visible cattle trails and dead stumps (>5 cm diameter) were recorded for each plot. Common and scientific names of all woody species where identified and recorded. Identification was done using Hedberg and Edwards (1995), Edwards et al. (1995, 2000), Azene et al. (1993).

In-depth interviews were also conducted with church priests, community leaders and guards. Furthermore, site visits with guided walks led by persons assigned from the churches and additional support from satellite images, served to document the physical features of the church forest systems. Focus group discussions were also conducted covering different groups such as elders, influential leaders within the community, women who are commonly engaged in fuel wood collection and youth who are frequently landless and I need of income.

Data concerning soil seed bank aspects at the various church forests and its contribution to restoration, as well as the number of livestock in the study area and their impact on seed germination and seed survival, are important aspects that need to be taken onto account. However, this is unfortunately beyond the scope of the study due to limitation in time and resources.

Data Analysis

Forest structure was described in terms of mean maximum height (calculated from the maximum height recorded in each sample plot), and mean basal area was as the sum of the cross-sectional stem areas of the overstorey plants and scaled to hectare (m^2 ha^{-1}). The density per hectare was calculated for the overstorey and understory plants. The species richness of trees was determined by counting the number of all woody species including seedling and sapling recorded in each sampling plot. The diversity of each church forest was estimated using the Shannon-Wiener Diversity Index (H) and Evenness or Equitability Index (E) (Magurran 1988).

Dominance was described in terms of Importance value index (IVI) which is a measure of the relative importance of a species in an area and combines relative density, relative frequency and relative dominance (Van Andel 2003). IVI is also an important parameter that reveals the ecological significance of species in a given ecosystem (Lamprecht 1989). Species with high IVI values are considered more important than those with low IVI value. The IVI values can also be used to prioritize species for conservation, and species with high IVI value need less conservation efforts, whereas, those having low IVI value need high conservation effort.

Results

Forest Composition

A total of 74 woody species (41 trees, 26 shrubs and 6 liana species) representing 32 families were recorded in the 10 church forests. From these species, 70 were indigenous Ethiopia and 4 were exotic. Fabaceae (7) and Moracea (3) families had the highest number of species. The total number of species and families in each of the 10 church forests ranges from 14 to 35 species. The mean basal area ranged from 6.39 to 17 m^2/ha and the mean number of seedlings ranged between 150 and 4150/ha. The average maximum height ranged between 16 and 45 m. The maximum stand density (7075 individuals' ha^{-1}) was recorded in Fisa Michael and followed by Aba Libanos (5254 individuals' ha^{-1}) and Zara Michael (4790 individuals' ha^{-1}) (Table 2). One species, namely *Diospyros abyssinica* dominated the woody vegetation in many church forests. For instance, it contributes up to 20–60% of the total density in six church forests and ranks as first in Gindatememl, Fisa Michael, Wolet Petros, Denbiso Abo, Zara Michael and Aba Libanos, and second in Wagira Mariam and Wonchet Michael church forests (Fig. 4).

Table 2 Area of forest (ha), Species richness, Mean basal area (m^2/ha, calculated from individuals with dbh > 5 cm), mean density (number of individuals/ha), average maximum height and IVI found in the 10 church forests

				Density/ha						
Name of church and forest	Forest area	Richness	Basel area m^2/ha	Seedling	Sapling	Tree	Total stem	Shannon index (H)	Evenness	IVI (Top 10)
Abune Aregawi	0.7	17	6.81	600	800	700	2100	2.45	0.87	207
Denbiso Abo	1.85	14	10.30	2450	525	725	3700	1.82	0.69	242
Wagira Mariam	2.5	16	9.61	1150	1650	375	3175	1.70	0.61	266
Aba Libanos	2.8	24	6.97	3927	964	364	5254	1.81	0.57	280
Wonchet Michail	6.2	23	11.92	150	475	258	883	2.69	0.86	181
Fisa Michail	6.9	21	17.81	4150	1438	206	7075	1.70	0.56	265
Woyebila k/miheret	7.43	35	11.86	2291	1268	514	4075	2.42	0.68	214
Zara Michail	8.3	24	15.52	4043	533	214	4790	1.96	0.61	277
Gindatemem	8.4	33	11.23	3448	830	256	4533	1.73	0.49	214
Wolet Petros	44.2	32	6.39	1205	910	750	2185	2.29	0.66	224

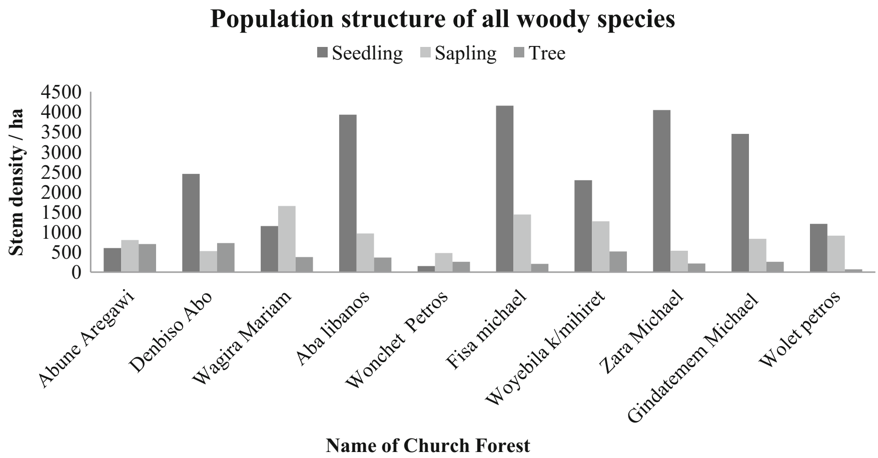

Fig. 3 The population structure of all woody species in ten church forest

Forest Structure

Based on structural features such as basal area, density and vegetation height, the forest differed broadly (Table 2). The population structure of woody species showed higher stem densities in the lower diameter classes (seedling and sapling) and progressively declining stem densities with increasing diameter classes (tree) in many of selected church forests. A greater proportion of individuals of all woody species, were found in lower diameter size classes, compared to larger diameter size in many of church forests. This forest condition resembles inverted "J" shape (Fig. 3). The population structure of some dominant species showed different population structure than the normal structure observed in all woody species (Fig. 4). *Mimusops kummel* and *Albiia shimperiana* showed broken "J" structure indicating a failure of reproduction. Species like *Celtis africana* and *Ehretia cymosa* showed broken inverted "J" shape, although there is relatively good early recruitment and establishment of seedlings but showing failure of further development to sapling and mature tree.

Species Richness and Diversity

The church forest varied in their species richness and diversity. Species number ranged from 14 to 35. The Shannon's diversity index was maximum in Wonchet Michail (2.69) followed by Abune Aregawi (2.45) and Weybila K/Miheret (2.42), while the evenness measure was 0.86, 0.87 and 0.68 respectively (Table 2). Only three woody species (*Diospyros Abyssinia*, *Millettia ferruginea* and *Croton macrostachyus*) were found commonly in all 10 church forests. Species richness and diversity values decreased with altitudes.

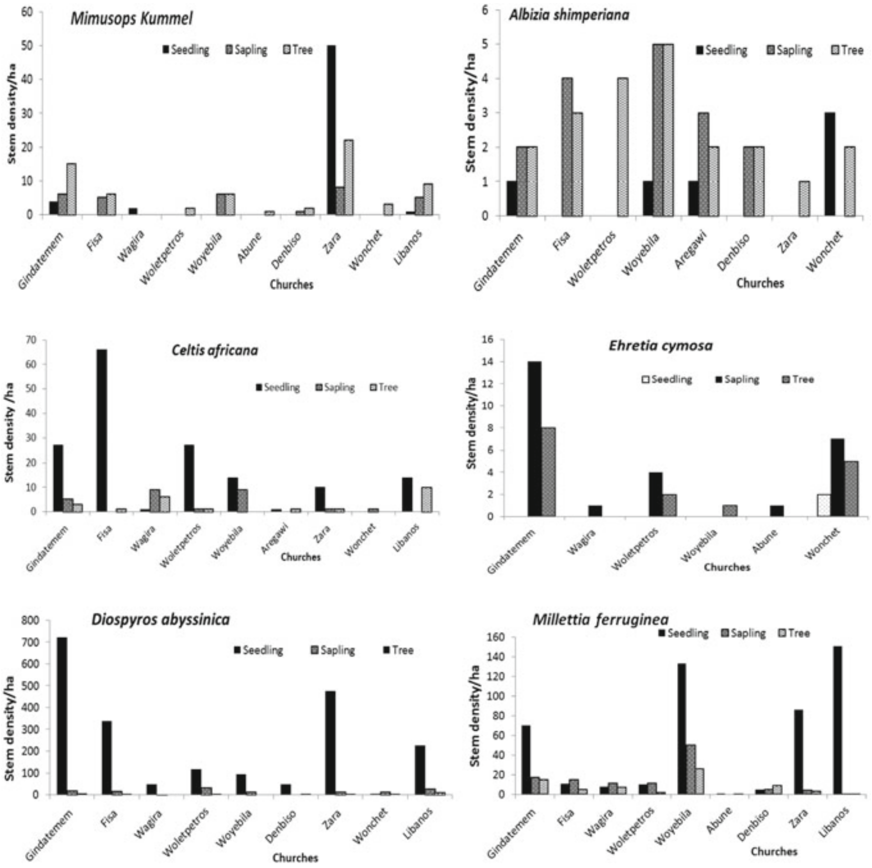

Fig. 4 Population structure of selected woody species in ten church forests

Discussion

Within the administrative zone of our study site (South Gondar administrative zone), more than 1404 church and monastery forests exist. The agriculture department of the administrative body reports that there are 125 woody species in the study area (SGAZDA 2004), but in our survey we found 74 species just from 10 church forests. Similarly, a study by Wassie et al. (2010) in the same administrative zone found 168 species from surveys conducted on 28 church forests. This implies the species richness of these church forests is massively underrated and more species are to be expected in other church forests. Hence, these church forests can play important role in conserving biodiversity as refuge and natural gene bank for seed productions especially in areas that are continuously threatened by deforestation and fragmentation.

Although the size of the assessed church forests varies from 0.7 to 44.2 ha, there was no indication regarding a trend between species richness and forest area. The absence of a relationship between species richness and forest area was also reported in other studies (Haig et al. 2000; Santos et al. 2007; Wassie et al. 2010). However, in some of the larger forest patches such as Wolet petros (44.2 ha) and Zara Michail (8.3 ha) slightly more species were recorded.

This could be attributed to ecological processes like island effects (Hill and Curran 2003) and also to sampling effects, in bigger forest patches containing more plots that sampled more of the community (Hill and Curran 2001). The edge effect could also be one factor why smaller church forests had still relatively higher richness. The edge effect may have increased the niches available inside the forest and disturbances favouring species in these smaller patches (Wassie et al. 2010). Even though larger patches of forest are important for maintaining a viable population, small patches or remnants forests role should not be neglected (Fisher and Lindenmayer 2002).

In our study, we observed a small trend in species richness decreasing with increasing altitude. Our finding is supported by an earlier study by Wassie et al. (2010) which found a similar decrease in species richness in 28 church forests. Other studies in the tropics also confirm species richness and diversity declining at higher altitude (Mohandass et al. 2017; Lacoul and Freedman 2006). When it comes to structural composition of the forests, human influence had a strong effect on all church forests except Zara Michael forest, which is fully protected with stone walls surrounding the entire forest boundary. Hence, Zara Michael had the lowest stump density compared to the other forests. The other forests typically faced high degrees of exposure to human and animal pressure. The majority of the shrubs and herbaceous species found at the external boundary of the forests are browsed or the seedlings are trampled. In the smaller church forests such as Aba Libanos, similar challenges were observed, but the threat was more severe as the forest area was very small and many tall trees were removed for construction and as income source for the church.

Local Communities' Perception Towards Church Forests

The various respondents stress the church forests as an intrinsic part of socio-religious practice within the Orthodox Christian religion. Even though they are important for religious and social services, they are not protected officially for their ecosystem services or biodiversity. Furthermore, they do not offer direct benefits to communities' livelihoods as for instance communal property or resources provide. Only nuns and monks who live or work in the church forest compounds benefit directly through collection of fruits etc. However, community members stress the significance of protecting the forest as it belongs to the church and this attitude of belonging to the church was found as a good deterrence against overuse of church forest resources at least in most of the forests (Klepeis et al. 2016). From an economic perspective respondent refer the benefits of the forest for collecting fodder grass, trees seeds and even seedlings, which can be bought directly from some church forests.

When it comes to the level of degradation, the community does not principally agree with the premise that the forests are degraded and in danger of being lost. Nevertheless, they emphasize on the lack of proper management and replacing cut trees with seedlings. Furthermore, the tendency of replacing indigenous tree species such as *Mimmusops kummel* or *Albiia shimperiana* with income generating species such as *Coffea arabica* or foreign species which have a direct negative impact on the ecology of the respective ecosystem like *Eucalyptus* spp. is concerning. Nevertheless, some respondents consider these procedures as the right approach for sustaining the churches financially. As future solution, the majority of the respondents suggested erecting stone wall around the forest for multiple reasons: Firstly, it can clearly demarcate the boundary of the church from the surrounding arable lands; secondly, it prevents cattle from ranging freely in the forest while disturbing the ecosystem severely, and finally it adds prestige to the church (Klepeis et al. 2016).

Application of the Results to Church Forest Management and Conservation

NABU's aim is to conserve the church forests at Lake Tana Biosphere Reserve as shelter sites for species and biodiversity and buffer against climate change impacts and to develop schemes for conservation and restoration of the church forests. Taking into account the main outcomes of the study and continuous discussion with the local community and church community, free grazing near the church forest, illegal deforestation and farmland encroachment towards the forest were identified as critical problems (Fig. 5).

Church forests have existed for hundreds of years due to strong but largely informal indigenous protection systems backed by the local community's shared religious values and traditions (Wassie and Teketay 2006; Klepeis et al. 2016). In addition, the recent establishment of the Lake Tana Biosphere Reserve will definitely help in ending the continuous cycle of ecological degradation in the area. Most of the church forests surrounding the lake fall within the biosphere reserve region. Ideally, this gives them further protection and makes them useful to restore deforested lands in the area (zur Heide 2012). In our study, we surveyed 10 church forests and found a total of 74 woody species and an indigenous tree such as *Prunus africana*, which is included in the IUCN red list of threatened species (IUCN 2006). Thus, these forests are very critical and serve as refuge for many indigenous species in the area. This makes the conservation of church forests as the priority in the biosphere reserve.

Following the study results and conducting intensive literature review, NABU implemented the conservation program on church forests successfully. The interventions focus on: (1) maintaining forest species diversity and ecosystem services by supporting efforts that help for regeneration of various species within the forest; (2) expanding the forest size in areas where possibilities exist; (3) creating buffer zones and interconnections between the church forests; and (4) establishing area closures to improve degraded areas.

Fig. 5 A stone wall fence surrounding a church forest at Lake Tana Biosphere Reserve (*Photo* Angelika Berndt)

Moreover, NABU in collaboration with the local community and the churches started erecting stone wall around the five target church forests. Stone walls have shown clear ecological benefits: (1) enhancing the regeneration potential by protecting seedlings from disturbance, reducing edge effects and grazing threats (Wassie et al. 2009) and (2) improving the floristic composition of the seedlings in the forest especially for species with low regeneration status such as *O. europaea* ssp. (Woods et al. 2017).

As part of the applied integrated approach to protect the church forests, a model of ecological corridors network has been developed to deal with the effect of fragmentation and loss of corridors between patches. Hence, the concept of interconnecting the selected five church forests by decreasing the distance between them and by creating buffer areas around them (such as area enclosures) as well as developing more vegetation patches in the landscape has been followed (Fig. 6). The selected forests showed clear potential for expanding them. Therefore, NABU together with the local administration and with active community participation started reforestation and enrichment planting with endemic species (e.g. *Mimusops kummel*) that show a low natural regeneration capacity and are under threat of disappearing. As it is also a keystone species, it can speed up restoration.

So far there is great enthusiasm among the leaders of selected church forests and local communities living in the vicinity of the churches. They have been actively engaging and participating in the conservation efforts and erection of stone wall. In the future, it will be important to monitor how effective the stone walls have been in

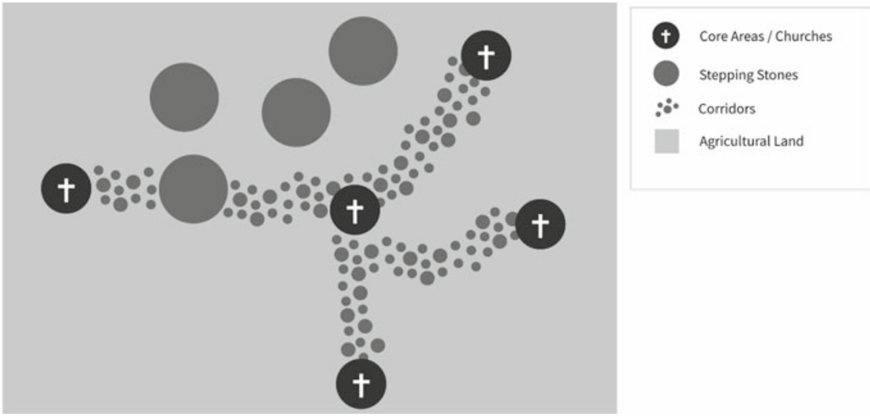

Fig. 6 Model of ecological corridors connecting church forests with steeping stones (NABU 2017)

the conservation efforts and how the regeneration potentials of these church forests have improved.

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Factors Affecting Communication and Information Sharing for Water Resource Management in Lake Victoria Basin (LVB)

Odongtoo Godfrey, Ssebuggwawo Denis and Lating Peter Okidi

Abstract Lake Victoria Basin (LVB) is a very important resource for the five riparian countries: Uganda, Kenya, Tanzania, Rwanda and Burundi. The basin provides resources for fishing, agriculture, medicine, forestry, water transport and other economic activities. However, its area is grossly affected by climate change due to population growth, urbanization, industrialization, increasing commercial activities and inadequate provision of sanitation services which have caused a lot of pollution. This climate change is likely to lead to loss of biodiversity in terms of species richness. Moreover, the increase in the population growth around Lake Victoria Basin is associated with an increase in economic activities that lead to ecosystem vulnerability and social-ecological disequilibrium. Climate change is likely to affect biodiversity as species struggle to adapt to climatic changes. In order to address the issue of climate change, proper communication and information sharing among the stakeholders around the Lake Victoria Basin is paramount. This paper addresses this need, by discussing major socio-economic activities taking place around this Basin, their impact on climate change and its impact on biodiversity thereof, and problems related to resource management. The study took place in the districts of Buikwe and Mayuge in Uganda. Qualitative and quantitative research approaches were used, data collected was analyzed using Statistical Package for Social Science research software. From the findings, there are variations in access to communication gadgets, mobile phones being top on the list of accessibility. The study concludes by identifying the best option for communication and information sharing based on the

O. Godfrey (✉)
Department of Information Technology, Makerere University, 7062, Kampala, Uganda
e-mail: godfreyodongtoo@gmail.com

S. Denis
Department of Computer Science, Kyambogo University, 1, Kampala, Uganda
e-mail: dssebuggwawo@kyu.ac.ug

L. P. Okidi
Department of Electrical and Computer Engineering, Makerere University, 7062, Kampala, Uganda
e-mail: plating@cedat.mak.ac.ug

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factors evaluated and recommends an integrated web-based and mobile application tool for better management of resource in Lake Victoria Basin.

Introduction

Lake Victoria is the largest fresh water lake in Africa with a surface area of 68,800 km^2 (EAC 2006). It is a very important resource for the five riparian countries: Uganda, Kenya, Tanzania, Rwanda and Burundi. The basin provides resources for fishing, agriculture, medicine, forestry, water transport and other economic activities. However, Lake Victoria Basin is facing problems of drastic climate change due to rapid population growth, urbanization, industrialization, increasing commercial activities and inadequate provision of sanitation services which had in turn caused a lot of pollution. Climate change is responsible for the deterioration of the quality of water and natural resources in the Lake Victoria Basin. Increased human activities, poor land use practices and pollution of water bodies greatly reduce the quantity and quality of the available water resources in the basin (Okurut 2010).

Without adequate intervention in the management of climate change in LVB, it is clear that the disadvantaged communities will continue to suffer. Managing scarce resources requires the application of appropriate technology, which is embedded in traditional knowledge and some inspired by fresh science research work and new insight (Mongi et al. 2010). Water resource management is the activity of planning, developing, distributing and managing the optimum use of water resources (Okurut 2010). In an ideal world, water resource management planning seeks to allocate water on an equitable basis to satisfy all uses and demands (Diggs 1991; Ssozi 2015).

This research arose out of the observation that there has been a steady population growth around Lake Victoria Basin (LVB), a change in climate around the Basin is manifested by floods, drought events, and sedimentation, etc. The population growth has over the years led to a number of socio-economic activities which have also contributed tremendously to climate change. Moreover, there is no ICT tool that can facilitate reliable information sharing among the local population and local leaders around the Basin. There was therefore a need to investigate and identify the major economic activities, the major energy sources, transport means, etc. that can lead to climate change. There was also a need to identify the available ICT tools currently used in the dissemination and sharing of relevant information about environment conservation around the Basin so as to avoid the effects of climate change on the ecosystems and biodiversity. This paper is one of the papers in which we intend to address the issues of climate change and its impact on biodiversity and developing a tool to address the gap in information dissemination and sharing.

Related Work

Climate in Lake Victoria Basin is continuously changing and it is getting worse as time passes. Bad periods are becoming more frequent than before, resulting in poor performance in agriculture and consequently food shortages in several areas in LVB. This has made farmers from different age groups to acknowledge the impact and are trying to adapt in different ways (Mongi et al. 2010). However, communities attempting to adapt to the adverse effects of climatic change are recognizing the potential role of information and communication technologies (ICTs) in responding to it (Ngonidzashe and Adekunle 2013).

According to East African Community Development Strategy Assessment (EAC 2006), it was revealed that communication and knowledge sharing are vital for water resources management in Lake Victoria Basin (LVB), and that at the moment, there are inadequate stakeholders' participation, inadequate communication and information sharing strategies; water quality monitoring and evaluation process is entirely manual. This had led to poor governance of the scarce water resource in LVB (Okurut 2010). Hence, there is a need to develop a tool which can be used by selected people and community leaders to timely communicate and coordinate activities of governance of resources in Lake Victoria Basin.

It is estimated that 200 tons of untreated effluents are discharged into the Lake everyday from economic activities around the lake (Okurut 2010). The problem affects millions of people whose livelihood depends on the natural resource base (UNDP 2007). Decline in volume of water in the basin may also have impacts on the socio-economic and political stability of the EAC. Some member countries are using LVB resources without consideration of its sustainability. Examples are; Jinja dam for Hydro-electric Power in Uganda and Shinyanga-Kahama water project in Tanzania (UNDP 2007). Management of resources therefore calls for an integrated approach, in order to address these challenges (Philippe 2011).

Rinawati et al. (2013) noted that climate change creates potential major threats to global biodiversity. The authors further observed that "the multiple components of climate change are projected to affect all pillars of biodiversity, from genes over species to biome level". This is true of the biodiversity around Lake Victoria Basin (LVB) which is threatened by climate change as noted by Case (2006). Case argues that because of climate change, the ecosystems and the livelihoods that depend on them are threatened. Muhweezi (2014) also noted that Biodiversity and ecosystem-specific goods and services in Uganda are likely to be adversely affected by climate change in the future. This he argues, is due to rising temperatures, which will increase by more than 2 °C by 2030.

Malcom (2003) and Green et al. (2003) noted that "recent reviews demonstrate a high confidence that climate change effects are already showing in living things. Despite this, there have been few attempts to model climate change impacts on biodiversity at the global scale".

Case (2006) further observed that the effects of climate change such as rising temperature and changes in precipitation are undeniably clear with impacts already affecting ecosystems, biodiversity and people. There are a number of socio-economic activities being carried out around Lake Victoria Basin. These not only affect the biodiversity, but also affect the management and governance of the water as a resource.

Weggoro and Ntamubano (2010), suggested that some of the practices in which governance of water resources can be improved includes; increase transparency through the provision of information concerning operating policies and procedures, programs, and projects to the general public. Information should be exchanged to stimulate debate, deepen understanding, and nurture new perspectives on transboundary environmental challenges and increase efforts to involve the public. Several conceptual frameworks have been developed to model the relationship between ICT and natural resources under climate change. These model suggests that governance of such natural resource has a chain of three major underlying components: methodologies, participation and results which are to be monitored and evaluated at different stages (Linuma and Tenge 2017).

Information and Communication Technologies have had an increasing impact on economic and social development, resulting from their capacity to generate and disseminate information to facilitate the coordination of different actors in and beyond government (Yonazi et al. 2012). ICTs are highly diverse and can be implemented on different scales such as sensor networks, satellite earth stations, meteorological systems and mobile phones that individuals can use to access information, report problems or share experiences(Ospina and Heeks 2010; Mongi et al. 2015).

Research Methodology

Study Sites

The study was conducted in Buikwe, and Mayuge districts. Measures were undertaken in choosing the type of community that contributed positively to research works through random sampling. The rationale for selecting these districts were based on three factors; First, their location within the Lake Victoria Basin. Second, the majority of its population depends on fishing, agriculture, charcoal burning, local herbs and water transport as their major sources of income. Third, the areas are vastly affected by decline in water resources and also the community's willingness to contribute towards achieving the project objectives.

Sampling Procedures

Researchers used probability and non-probability sampling methods. In probability sampling, simple random sampling was employed to come up with representative of community members from the two villages. In non-probability sampling, purposive sampling method was employed to select key informants who provided key information on LVB. These are people who are knowledgeable on climate matters, examples, Community Development Officers, Environmental Officers, Law Enforcement Officers, and NGOs working on environments and other poverty eradication program.

Population Size and Distribution

A sample size of 89 respondents from two study areas in Buikwe and Mayuge districts was selected using Morgan and Krejcie (1970) tables. Both purposive and stratified random sampling procedures were used to ensure representation of all relevant stakeholders to ease reliability and efficiency in data collection. There were 30 key informants and 59 community members.

Data Collection Methods

Primary data collection was done through questionnaires survey using structured questionnaire, focused group discussion by using prepared guide questions and key informants interview by using interview guide. Questionnaire method for data collection helped to collect a lot of information in a short time. This enabled the researchers to find out ready information easily for the study. Focus group discussion were done through inviting village people such as agricultural extension workers, commercial farmers, peasant farmers, fisheries, cattle keepers and other community workers. This aided an efficient digging of information through interaction. The pertinent concern including why there still exist illegal cutting of trees for charcoal and firewood, illegal fishing tools and corruption was clearly identified.

Reliability and Validity of the Research Approach

To address the issue of reliability, questions were checked to determine if they are prompting the types of responses expected. A pilot test with a small set of people from the target population was also done and the tools were found reliable. The observation protocol/record keeping sheet was also critical in getting credible data. Three experts in the study area of the research (expert in water resource management and climate change) were used to check and provide guidance on the questionnaire used as a data collection tools.

Data Analysis

The statistical tool, SPSS, was used to generate descriptive statistics and other results as discussed in the next section. Content analysis was used for Qualitative data by which they were categorized into major themes related to research.

Results

Respondents' Characteristics

As shown in Fig. 1, majority of the respondents were male (71.4%) while 28.6% were females. 44.8% of the community members were in the age group 36–50 years. 37.7%

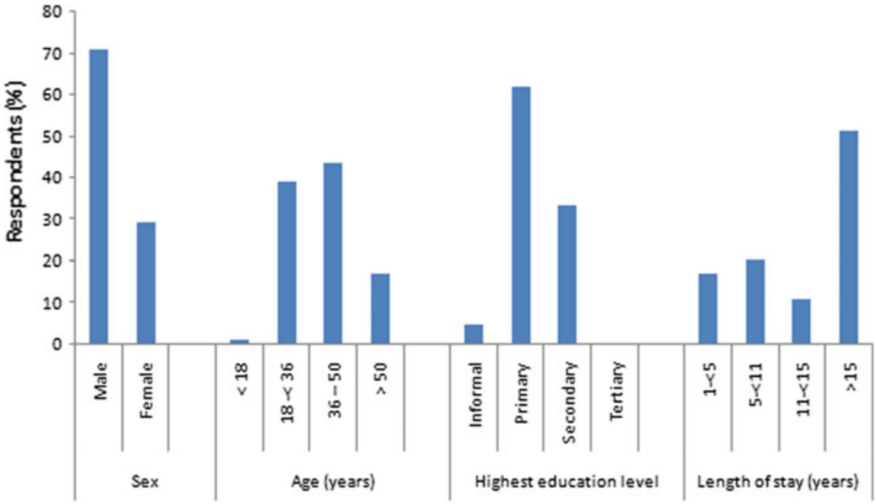

Fig. 1 Respondent characteristics

of the community members had secondary school education; 22.6% had tertiary education. Most of the respondents (81.3%) had stayed in their current places of residence for over 15 years. Low level of education has a impact on the use and adoption of technologies.

Major Economic Activities

As shown in Fig. 2 below, the major economic activities are crop production (47.2%), fishing (16.3%), small businesses (10%), Wage Laborers (4.5) and Livestock keeping (7.5).

Most of the respondents are involved in crop production and fishing.

ICT Facilities and Uses

As shown in the Fig. 3 below, the most accessible ICT facilities are radio (48.9%), mobile phone (52%) and TV (13.1%). Access to internet is low (2.7%) and computer (2.7%). Community access to information on LVB water resources is low (44%).

Owners of Transport Asset

As shown in the Fig. 4 below, most of the community members use bicycles for transport (32.6%), boat (5%), motorcycle (4.5%), motor vehicle (1.8) and Boat (5%). There is a big problem of transport as the majority rely on bicycles to facilitate their movement. As a result, field officers working for Governments, NGOs, in the management of water resources become less effective in performing their duties.

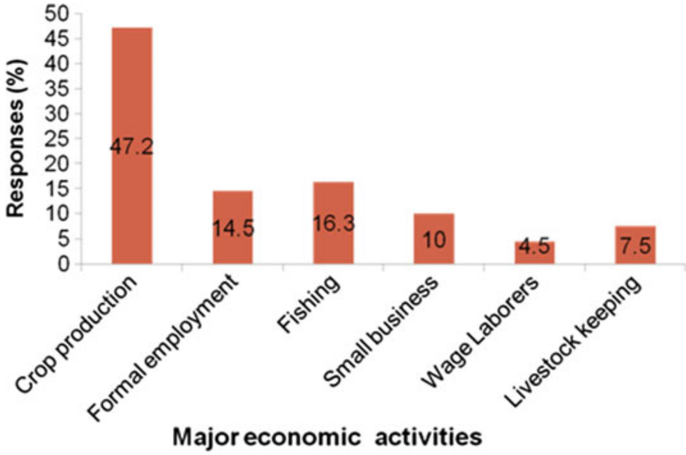

Fig. 2 Major Economic activities

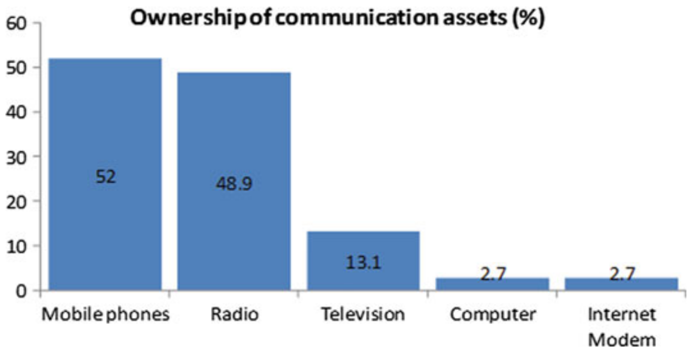

Fig. 3 ICT facilities

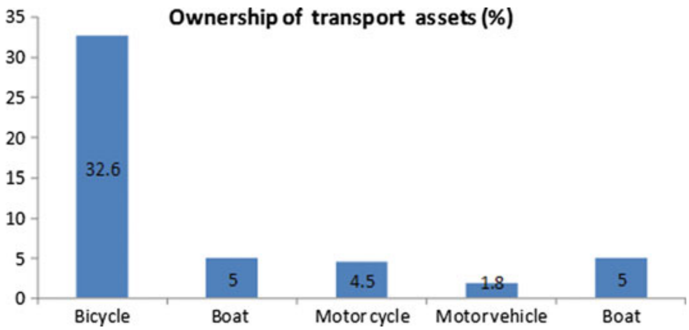

Fig. 4 Methods of transport

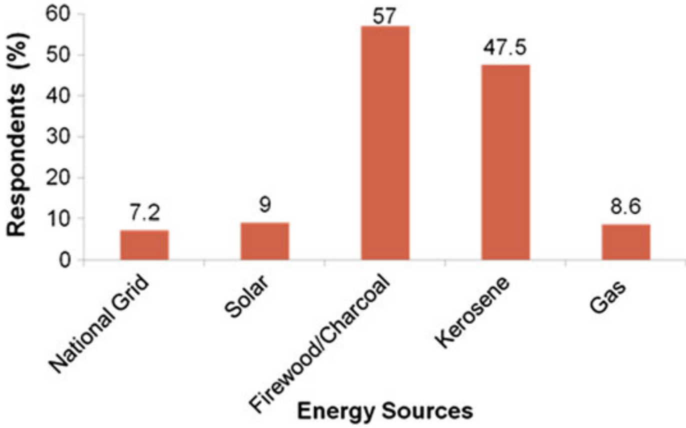

Fig. 5 Energy source

Major Energy Sources

Figure 5, shows major household energy sources: Kerosene (47.5%); firewood/charcoal (57%); grid electricity (7.2%), solar (9%) and Gas (8.6%). The most accessible and widely used energy source is firewood/charcoal. This could be because the electricity is still very expensive for the community as well as solar and gas. The results of forest cover depletion is felt as people cut down trees for firewood and charcoal.

Major Governance Issues for Sustainable LVB Water Resources

Figure 6 shows governance issues rating (1–3) in relation to degradation, inadequate participation, lack of transparency, lack of equity, lack of coordination, corruption among officials and climate change.

Perceived Benefits of LVB Water Resources

The perceived benefits of Lake Victoria basin were; income generation (28.8%), food source (28.8%). source of water supply (22%), Tourism (8.3%), Construction sand (5.1%), Timber (3.4%), Weather (10.2%).

Community Perception on Major Causes of LVB Water Resources Degradation

The community perceptions on the causes of Lake Victoria Basin water degradation are; poor governance, high population, deforestation, poor farming methods.

Key Informant Perception on Major Causes of LVB Water Resources Degradation

The key informant perception on major causes of Lake Victoria Basin water resources degradation is; illegal fishing activities, negligence of people, lack of employment, poverty, inadequate knowledge, industrial activities, limited community participation and awareness, mining activities, poor enforcement of laws and regulations.

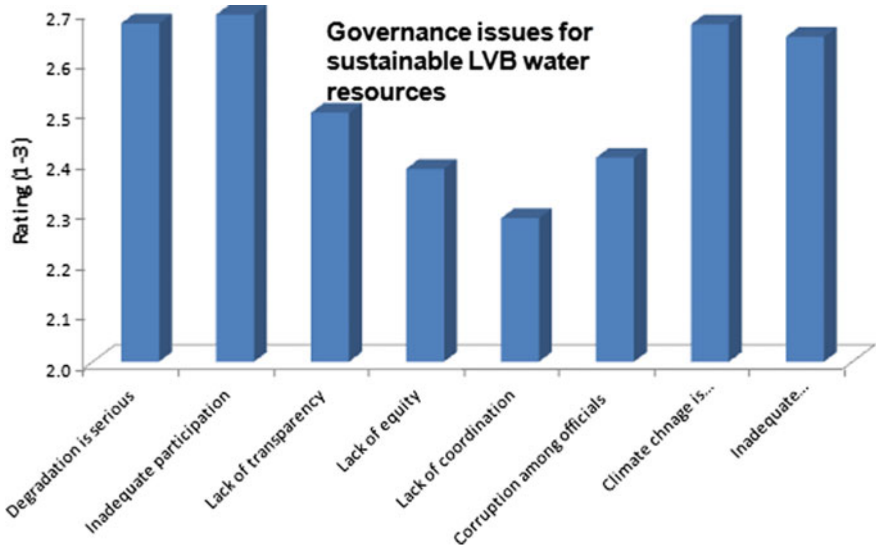

Fig. 6 Major governance issues

Weaknesses in Existing Policies on LVB Water Resource Management

Major Weaknesses in the existing policies on Lake Victoria Basin resource management are; Lack of enforcement of laws, Limited community participation and awareness.

Discussion

Since there is low level of education as indicated in the results, the design of ICT technologies needs to be user friendly, and must be community oriented if success is to be achieved. The fact that the majority of the respondents stayed in their current place for a long time, implies that they have really felt the effect of climate change and their report was therefore trusted.

The most accessible ICT facilities are mobile phones (52%) and the access to internet and computer is still low (2.7%). Given this situation in mind, the success of any resource management tool for community, should be developed under community context and therefore consideration on the gadgets owned by those people is worth mentioned. Hence, the system should integrate internet and mobile phone.

Most of the respondents are involved in crop production and fishing. The increase in population around Lake Victoria has a big effect on the forest cover as people clear bushes to pave way for crop production hence resulting into adverse effect of climate change. Also fishing practices need to be totally streamlined as many people get involved as a way of survival because of lack of employment.

The major accessible household energy source is firewood/charcoal (57%) while the lowest is Gas (8.6%). This had again impacted on forest cover since the growing population cut down trees indiscriminatively for charcoal and firewood. The little use of electricity could be due to it being expensive which is not affordable to the local community. Governance issues in relation to degradation, inadequate participation, lack of transparency, lack of equity, lack of coordination, corruption among officials have been found as a serious problem. The proposed ICT technology will curb down this vices by adequately aiding the community participation and efficient implementation of policies on LVB.

Limitation and Constraints of the Study

Lake Victoria Basin covers five countries including Uganda, Kenya, Tanzania, Rwanda and Burundi. For this exploratory and preliminary study it was not possible to visit all the countries of the East African Community (EAC) due to logistical constraints. However, this will be the case in future when the current logistical constraints are solved. There was apprehension from some of the research participants who never wanted to be interviewed or fill the questionnaire having known that the research is about the activities they are involved in around the Lake. This took the researchers a lot of time to identify willing participants to take part in the study.

Conclusion, Recommendations and Further Research

Conclusion

This study examined the challenges being faced and the impact of climate change on water resource and biodiversity around Lake Victoria Basin. A number of major economic activities and energy sources were identified and these have been found to have an effect on climate. It was also discovered that participation of all stakeholders in the governance of water resources is paramount if success in curbing down challenges facing water bodies due to adverse effect of climate change is to be realized. Furthermore, it revealed that there is no way participation in governance can be achieved unless there is a reliable communication system in place. Since stakeholders are different and complex in nature, and given the fact that they are equipped with different communication gadgets, there is need for an integrated system to bring all persons on board which will enhance water resource governance in LVB. Also, the studies noted that there are weaknesses in the enforcement of policies as well as little awareness of those policies. This could be so, because of lack of reliable communication platform which can help stakeholders to share and coordinate information on governance. The government and other non-state actors should invest more money to produce a reliable communication system to coordinate the activities of governance.

Recommendations

The proposed recommendation to curb down challenges affecting Lake Victoria Basin is; improved enforcement of rules and regulations, high community involvement in the management of water resources, awareness creation, fight against corruption and improved communication among stakeholders. We recommend that a system should be developed to enhance effective communication at all levels of governance. According to the findings, the most communication gadgets available to the population that are commonly in use are; Mobile Phones, Internet, Radios and Television sets. This implies that the ICT tool to be developed should incorporate at least two of these communication gadgets.

The researchers recommend an integrated mobile application tool which will incorporate mobile phone, internet and web-based in one platform. This tool will be used by selected people such as key informants, community leaders, Government workers concerned with LVB, NGOs etc. in enhancing management of water resources in LVB.

Lessons Learned and Further Research

This study revealed that majority of the people around the Lake Victoria Basin are unware of the dangers posed by their economic activities. Moreover, the local leaders lack effective and efficient means of disseminating and sharing the information about the dangers brought about by climate change and its impact on the ecosystems, biodiversity and the water resource.

Areas for further research include developing an ICT tool that integrates all the available communication channels. This tool will be used to enhance communication, dissemination and sharing of information about methods and procedures that can be taken to preserve and protect the shores and waters of LVB.

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Climate Sentinels Research Program: Developing Indicators of the Effects of Climate Change on Biodiversity in the Region of New Aquitaine (South West, France)

Fanny Mallard and Laurent Couderchet

Abstract Understanding local effects of climate change on biodiversity are essential for environmental policy orientation. Lacks of knowledge at regional level have led to the development of a research program: "Climate sentinels" (www.sentinelles-climat.org). A research hypothesis is that the effects can be studied from indicators of species that have weak displacement. These "sentinel" species will be the first to respond to local climatic variations by adaptation or local extinction. In France, New Aquitaine region is a relevant research laboratory. It offers both sensitivity to climate change and a variety of natural ecosystems. The approach to understanding the response of these indicators to climate change is based on observations in a whole region, standardized protocols in relationship with models using mainly abundance data, validated data linked to associated sufficient coverage and relevant observations in connection with time and space scales. In this paper, we will present 3 points characterizing this project: (1) the research-action approach of the program brings together different types of actors (decision makers, naturalists, managers, researchers and the public), within an independent organisation and catalyst "Cistude Nature", (2) the method of establishing a list of development indicators called "Climate sentinels", (3) the protocols and data analysis of multi-ecosystems, multi-species at different scales that are used to support projections of climate change impacts on biodiversity. The aim is to share feedback on this topic concerning the structuring of the program at the interface between science and society.

F. Mallard (✉)
Cistude Nature, Chemin du Moulinat, 33185 Le Haillan, France
e-mail: fanny.mallard@cistude.org

L. Couderchet
University of Bordeaux-Montaigne, Passages—UMR 5319 CNRS, Maison des Suds—12, Esplanade des Antilles, 33607 Pessac Cedex, France
e-mail: laurent.couderchet@u-bordeaux-montaigne.fr

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Introduction

The complex influences of climate on biodiversity and the intrinsic adaptive responses of species are still little followed and unknown (Berteaux et al. 2010). Effects specifically related to climate change are difficult to highlight because of the multiple factors to be taken into account such as lack of knowledge about interactions and species adaptation, on observation results done only locally and over too short periods of time. The example of terrestrial ecosystems illustrates this multiplicity of pressures, impacts and interactions. In particular, the dual pressure of climate change and land use are confusing the understanding of the impacts of climate change (Mallard 2016a). The organisms are confronted with these cumulative effects of multiple disturbances. If the dissociation of effects is not really feasible, it is possible to choose systems that give access to the effects of climate such as protected, natural environments, ectothermic animals whose ecology and physiology are directly dependent on amñbient thermal and hygrometric conditions.

The lack of knowledge and data is progressively reduced thanks to long-term observations, the improvement of understandings of ecological processes, data processing techniques, and the choice of various and complementary models. In practice, understanding the response of biodiversity to climate change in order to implement conservation strategies requires: (1) to combine regional and local space scales, time series data for biodiversity and climate (Root and Schneider 2006) to provide elements of knowledge for the implementation of actions by the local natural areas managers but also to the regional decision-makers driving forces (Berteaux et al. 2010), (2) to perform observations, protocols fields related to models with abundance data, (3) to provide validated data, associated sufficient coverage, scalable campaigns based on these data, and relevant observations linked to time and space scales, (4) finally to communicate aggregated information to different actors.

Today, there is no long-term monitoring, indexed, and standardized allowing a global analysis of the impacts of climate change on biodiversity state at the regional scale. These shortcomings lead to new research approaches that extend the work of monitoring species populations. Being aware that these gaps must be filled as a priority, the Cistude Nature association has created links with partners to set up a multi-year study program: “Climate sentinels” (2016–2021). The challenge is to move forward fundamental knowledge by reasoning in terms of multi-scale space and time operation. In this context, it is essential to know and to take into account variables coupled in space and time, to combine different theoretical disciplines from various field studies, by facilitating the analysis and the multi-public circulation of knowledge. This program raises the following question: *How to assess and predict the response of regional biodiversity to climate change?* A research hypothesis is that the effects can be studied from indicators of species that have weak displacement. At a regional or local scale, the most endangered species are those with latitudinal and altitudinal spatial restrictions and limited dispersal capacity (Feehan et al. 2009). These “sentinel” species will be the first to respond to local climatic variations by adaptation or local extinction.

In this paper, the first part describes a research approach responding to this problem in a new discipline of ecology to be developed, which would be first of all a science of climate-biology relations: the ecology of climate change. The second part identifies the scientific perspectives for the development of indicators monitoring the effects of climate change on terrestrial ecosystems through the search of species or groups of species that are sensitive and indicative of this climate change. The identification of these sentinel species of climate requires the choice of a study area that is coherent at the biological level, but also for biodiversity conservation actions and for the dissemination of knowledge. The terrestrial ecosystems of New Aquitaine region (France) are selected according to ecological, climatological and topographical criteria. Finally, the third part presents the approach of global analysis of program indicators and the modelling of spatial distributions and future projections of species in the face of climate change. The ecological data used come from two types: species presence data from existing regional observatories and abundance data from sampling protocols implemented specifically. Three universal responses of these plant and animal species are studied and are based on changes in distribution, physiological and phenological adjustments (plasticity) or micro-evolutionary phenomena (selection) (Daufresne et al. 2009).

The purpose of this paper is to share a feedback on how this program is structured (after a first year of implementation), how to address the issue of climate change and biodiversity at the interface between science and society. The project "Climate Sentinels" presented is reproducible. The methods and models developed in this program could be referred to discussion, generalized and applied in other territories at both national and European level to increase knowledge of biodiversity. The methods put in place, the data processing tools and the reflections around the formation of a community of actions, whose role is to act on the political orientations, consider a standardization process and allow a transposition to other territories. The aim is to strengthen the links between researcher community and naturalists, natural areas managers of and the decision-makers who implement environmental policies, as well as the general public which guides societal choices. The scale of study brings together the actors of the region level. This scientific exercise is part of epistemological change context. We hope this shared experience will promote, inspire and export this initiative to other territories.

Research Approach

Hypothesis and Objectives Related to the Problematic

Answering the problem requires identifying relevant and operational indicators at a regional level (New Aquitaine, France) to assess the state of biodiversity, to project it and to try to predict the biodiversity response to climate change. The indicators allow a reduction in the number of measurements and parameters, thus simplifying the approach of complex, interdependent phenomena. Their function is to describe, distinguish, simplify, aggregate, evaluate and be a basis to project the impacts of climate change on biodiversity. For biodiversity indicators, the objectives are also multiple. They make it possible to evaluate at the same time, the viability, the durability, the resilience, the productivity and the vulnerability. In short, to take stock of the state of health of biodiversity and to allow users to make decisions and evaluate the consequences.

As a result the indicators used are "biological" and concern species (or groups of species) of flora and fauna studied in their environment. The status and evolution of these indicators are related to a set of meteorological and climatic parameters at different time and space scales. These data concern temperature, hygrometry, rainfall, solar radiation and wind speed, in order to identify trends in the impact of their variations on the state of biodiversity.

Three types of impacts of climate change on biodiversity are currently recognized: (1) expansion, persistence of the species to the modified climate in the habitat (genetic adaptation, phenotypic plasticity), (2) slippage, migration to more appropriate refuge areas or (3) contraction, local extinction, collapse, decline (Davis and Shaw 2001).

The number of local extinctions will strongly depend on the ability of the species to move (Foden et al. 2008) or to adapt. At the regional or local scale, the most endangered species are those with latitudinal, altitudinal spatial restrictions and limited dispersal capabilities (Feehan et al. 2009). Amphibians, reptiles, micromammals and some invertebrates have lower movement capabilities than large mammals or flying species. We hypothesize that these species should be among the first to respond to local climatic variations and thus constitute "Climate sentinels". On the other hand these species, not very mobile, are generally easily observable which allows for simple and less expensive study protocols. In addition, they generally have an affirmed heritage aspect.

From these indicators, two main objectives are then distinguished:

- The first is ecological and determines the potential effects of climate change by dissociating them from other anthropogenic factors by monitoring the status of these sentinel species. Most of the impacts on species will be detected over time, in relation to their intrinsic response time and changes in climate change. These effects cannot be detected easily in the field over a short time, which implies observations of greater sensitivity and in sufficient quantity in the early stages.
- The second is biogeographic. On the basis of these data and associated models, it is necessary to evaluate, characterize, at different local and regional scales, the response of these sentinel species of the climate.

Action Research

To describe the complex relationships between society and the environment, a possible framework of reasoning is to rely on the analysis model called "DPSIR" Driver (D)—Pressure (P)—State (S)—Impact (I)—Responses (R) to provide a method for understanding synergies between the effects of climate change, ecological processes, political decisions and management actions (Smeets and Weterings 1999). It allows to describe, to classify the origins, the causes and the consequences.

A first stage of the framework lists all disturbances on the natural elements of the landscape. The "Drivers" correspond to the driving forces mostly related to human activities. The actors who influence these forces are ultimately the general public. These decision makers who implement policies including environmental. The decision makers of the program (here European Union, Region New Aquitaine, departments of Gironde and Pyrénées-Atlantiques) are financers and support the program. Even these driving forces cause pressures ("Pressure") of various natures, climate change is an impact which becomes a pressure component from a biodiversity point of view.

The second step involves monitoring the state of natural ecosystems based on the presence, abundance of animal or plant species that live there and are subject to these pressures. Information from this state is collected by naturalist experts of the program. The essence of this monitoring is to take into account all "impacts" or spatial-temporal effects, including those induced by the "climate" component. The state first takes into account the vulnerability, gap between its levels reached and its limit level, but also the resilience of the ecosystem. Next, projections of the impacts of climate change on biodiversity over time are essential for the development of conservation strategies. They are largely derived from bioinformatics analysis strategies, involving spatial-temporal modelling of each species, each functional group, each community, and ecosystems. Academics and research laboratories in collaboration with Cistude Nature develop the modelling part.

This last approach becomes a meeting point between applied research and basic research, between those who experiment, provide data and those who model, increase, aggregate information. The coupling of the two approaches (bottom-up/top-down) allows a so-called "hypothetico-deductive" approach. The process consists of formulating a hypothesis in order to deduce observable consequences (Fig. 1) and these observations in turn determine their validity. Although complex to set up, the scientific literature encourages hypothetico-deductive approaches by frequently linking field studies, models and experiments in order to attest to a causal and not only correlative association between climate change and decline of biodiversity (Pradervand et al. 2014).

Finally, with this DPSIR framework, the final step is to evaluate the effectiveness, and to identify adaptation and mitigation actions to climate change effects to implement. This step also helps to explain, and to sensitize, in short to carry out a mediation work with a large public that influences implementation of the measures

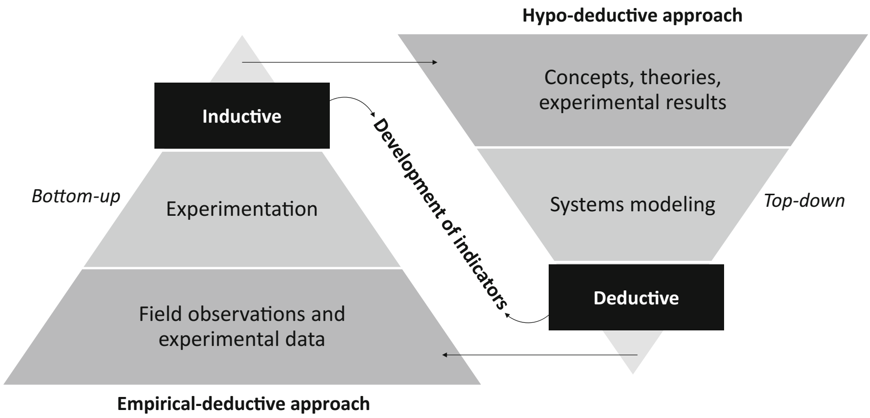

Fig. 1 Bottom-up and top-down approaches in ecology for indicator research (Mallard 2014). The "top-down" and "bottom-up" approach makes it possible to formalize relevant leads on what it would be interesting to study for indicators search. The coupling of the two approaches becomes a hypothetico-deductive approach which consists in formulating a hypothesis in order to deduce observable consequences, allowing to determine in return its validity, by field data, experimental values. This program context becomes a scientific meeting point between applied and basic research leading to action research between managers and scientists

decisions, in particular by the choice of the political programs ("Responses"). This approach leads to an "action research" at the interface between science and society.

The resources put in place in this program promote a coordinated work that links the different disciplines of study. In practice, the "Cistude Nature" association, (an association under the Associations French Act 1901 status), approved at the regional level for the protection of nature, has a mediating role to mitigate the institutional or language barriers between academics and naturalists. It is also the coordinating structure at the interface between science and society. The association becomes a privileged link between the decision-makers and those who carry out naturalistic expertise. It develops, in co-partnership, modelling with researchers. Through its Scientific Council, it ensures the validation of methods and proposes communication and mediation tools for all audiences (Fig. 2).

Development of Sentinel Climate Indicators

Climate Change Effects State of Art

To develop sentinel climate indicators, a first step is to carry out a structured bibliographic inventory in order to identify groups sensitive to climate change. A state-of-the-art knowledge of the effects of climate change on biodiversity on a

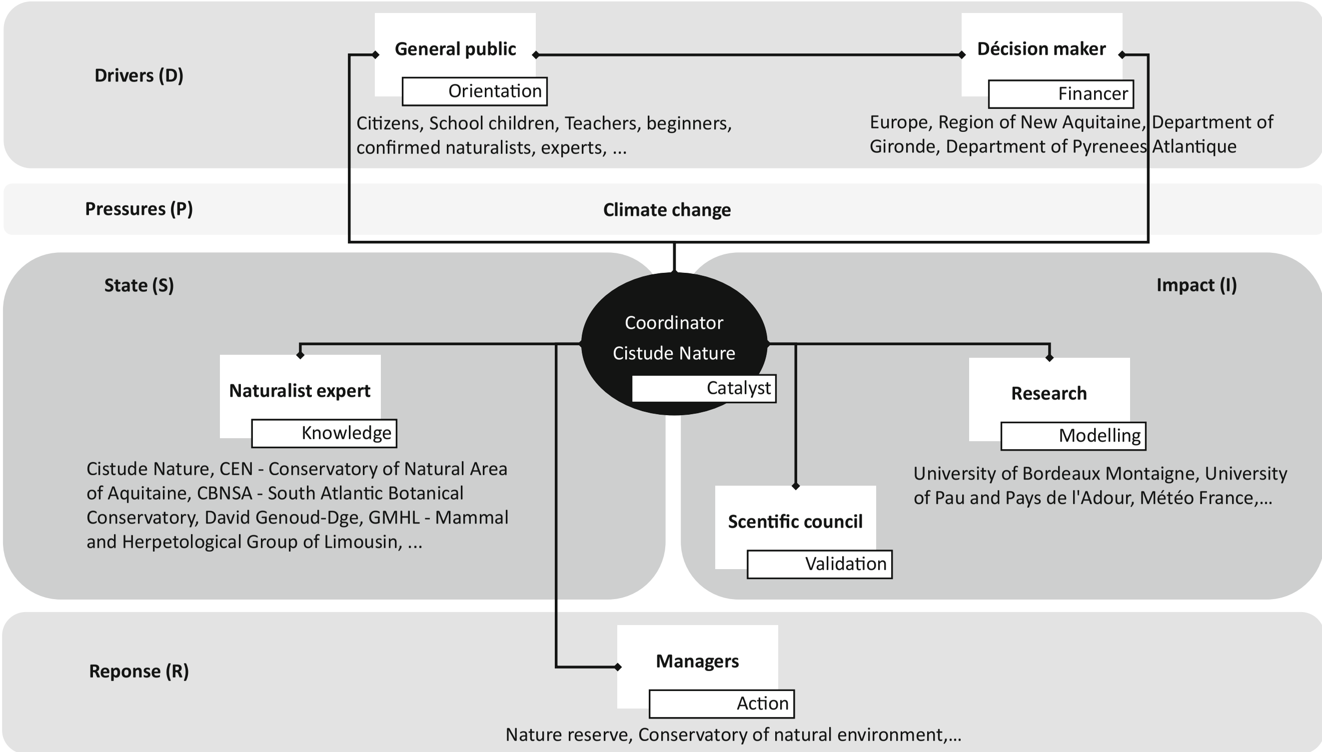

Fig. 2 Science and Society Interface Model of the Climate sentinels program. The program is part of an action research approach at the interface between science and society. Cistude Nature is an independent association which coordinates the program. It helps to create the links between researcher community and naturalist, natural areas managers of and the decision-makers who implement environmental policies, as well as the general public which guides societal choices. This structure has a mediating role to mitigate institutional or language barriers between academics and naturalists. The associations collect the data (bottom-up approach). Researchers analyse and model the data (top-down approach)

global scale was therefore realized as part of the program. Groups of indicator species commonly used to characterize the state of the environment were identified: mosses, ferns, Gymnosperms and Angiosperms, insects (Bumblebees, Odonata, Lepidoptera), amphibians, reptiles (lizards) and small mammals (rodents, Alpine Marmot) (Mallard 2016a).

This bibliography, available on the website of the study (www.sentinelles-climat.org), shows that climate change is a pressure that affects the structure and dynamics of ecosystem functioning through a wide range of effects that can be classified according to their nature and characteristics: direct, indirect, induced and temporary, permanent and cumulative (Fig. 3):

- Direct effects are the major ones directly related to climate change that unequivocally influence key ecosystem processes,
- Indirect effects come from the retro-action combination of direct effects, which tend to increase them at different spatial-temporal scales,
- Induced effects are derived from anthropic responses that are related to the measures put in place related to political decisions,
- Cumulative effects include in summary the interaction of direct, indirect and induced effects. Other anthropogenic factors will synergize positively or negatively with climate change and increase pressure on species survival (Kremen and Ostfeld 2005).

Climate Sentinel Species

Following the bibliographic synthesis, it was necessary to define study areas to identify indicator species. These different geographical areas have varying intensities of climate change (GIEC 2013). They contain species with different sensitivities to the pressure of climate change (Bertin 2008; Li et al. 2013). In France, New Aquitaine region is an open-air study laboratory in the sense that it is both particularly sensitive to climate change, with contrasting local climatic zones and a wide variety of natural ecosystems (Le Treut 2013; Mallard 2016a).

Rare species are not only those that are the most sensitive to climate change. The common species of a taxa, because of its specific variability, are also sensitive to this evolution (Pearman et al. 2011). The state of the art of knowledge (Mallard 2016a), defined criteria and a large empirical database of flora atlas productions (atlas online: ofsa.fr) and fauna in Aquitaine (atlas online: si-faune.oafs.fr) (Berroneau 2015; Ruys and Couzi 2015; Gourvil et al. 2016), indicator species and groups of species have been developed for 5 types of climate-sensitive ecosystems (Fig. 4): dunes, dry, wet, forest and mountain.

From this territory, in summary below, 20 indicators of climate change in the different ecosystems were chosen. The evolution of floristic process indicators will be followed for each of these natural environments. Within these ecosystems, the following animal species are studied: insects (Lepidoptera, Odonata, bumble-

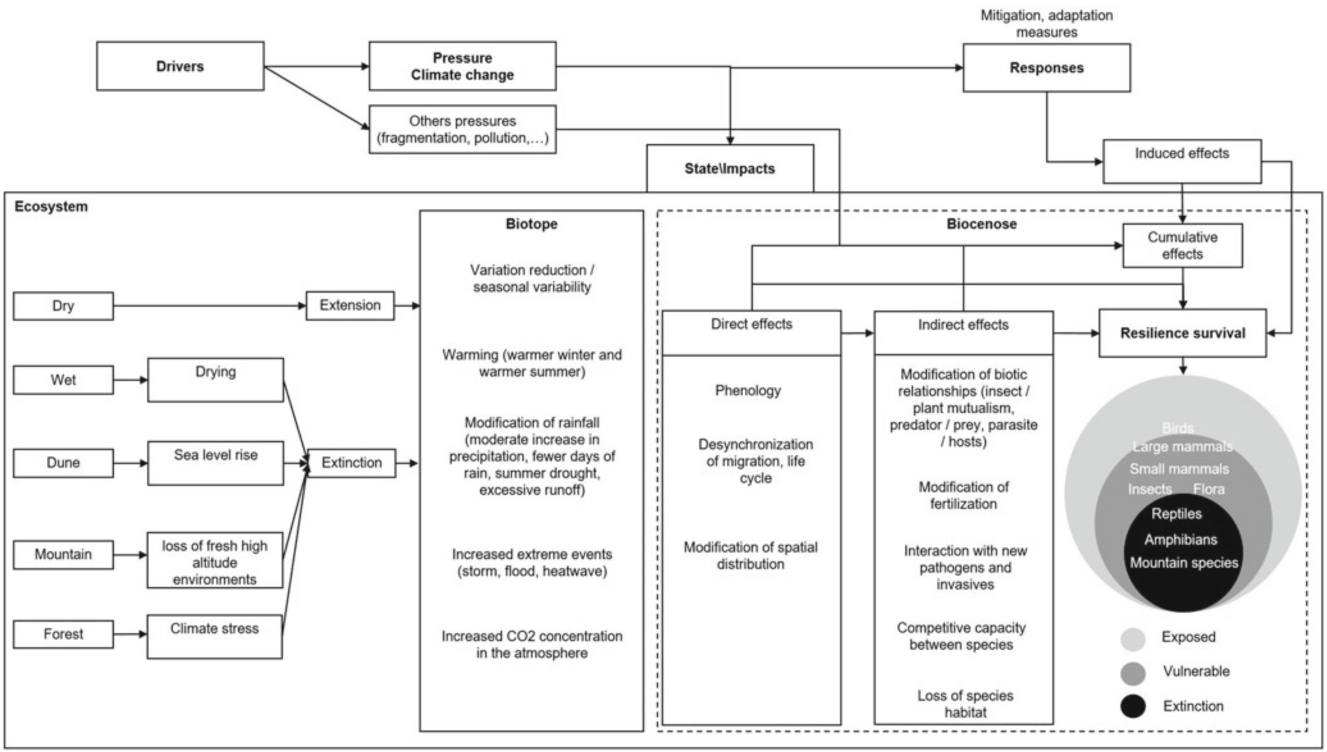

Fig. 3 Effects of climate change on the components of ecosystem (adapted from Mallard 2016a). Climate change is a pressure that affects the structure and dynamics of ecosystem functioning through a wide range of effects that can be classified according to their nature and characteristics: direct, indirect, induced; temporary, permanent; cumulative. According to the bibliography, animal and plant species can be classified according to their sensitivity to climate change: exposed, vulnerable, extinction

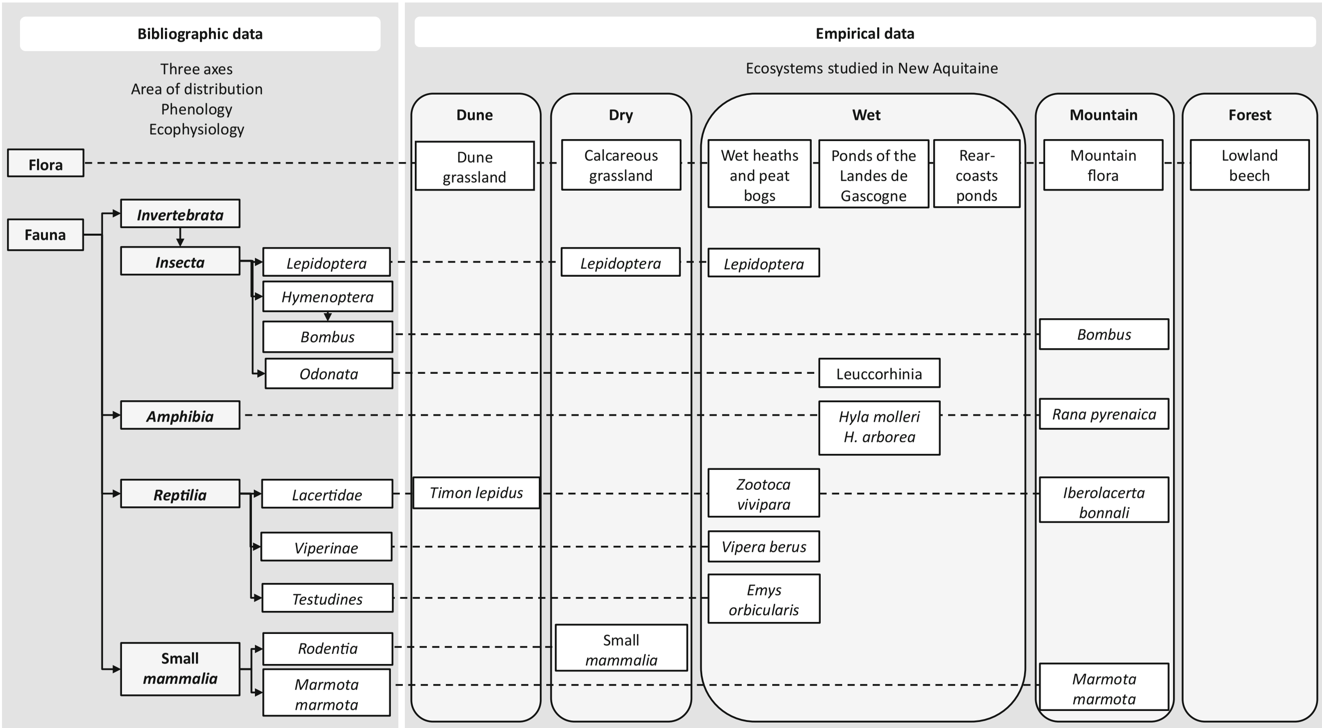

Fig. 4 Steps for developing indicators of species and groups of species that are indicators of climate change (adapted from Mallard 2016a). From the bibliography synthesis, defined criteria and large empirical database of atlas productions of flora and fauna in the New Aquitaine region, species and groups of indicator species have been developed for 5 Ecosystems types, sensitive to climate change: dunes, dry, wet, forest and mountain

bees), amphibians (*Rana pyrenaica*—Pyrenees frog, *Hyla molleri*–Iberian Tree Frog and *Hyla arborea*–green), reptiles (*Iberolacerta bonnali*—Pyrenean Rock Lizard, *Timon lepidus*—Ocellated lizard, *Zootoca vivipara*—Viviparous lizard, *Emys orbicularis*—European Pond turtle, *Vipera berus*—Viper peliad) and small mammals (*Marmota marmota*—Alpine Marmot, small mammals) (Fig. 4).

Program Analysis Plan

These 20 indicators in the 5 selected ecosystems form the basis of the "Climate sentinels" study program for long-term analysis and monitoring of the effects of climate change on biodiversity in New Aquitaine. The originality of this program lies in the monitoring of multi-ecosystems, multi-species over time and at the 84,000 km^2 scale of the region. This last part describes the modelling process implemented which is part of the program, according to French geographer Roger Brunet: we must go through a model to understand and be understood (Brunet 2000). Based on the exploitation of bibliographic data and specific collected data within the framework of the program, the modelling objective is to evaluate the forecast responses of the sentinel species.

Modelling does not start with computer model, it starts as a schematization. A model is a simplified representation of a reality. To be relevant, the first step is to understand and justify its incoming and outgoing. Thus, a very flexible model without ecological justification will give biased predictions and significant uncertainties (Araújo and Peterson 2012; Bell and Schlaepfer 2016).

In order to visualize what we had to consider as factors, and the answers we expected from the model, we give a reflection scheme which summarizes it (Fig. 5).

Naturalistic Data from Regional Observatories

In order to study the effects of climate change on biodiversity at the regional scale, the collection of information in the field requires many observations to obtain significant results. The regional observatories are tools allowing access to a mass of naturalistic observations validated and distributed throughout the territory (Bœuf et al. 2012). In New Aquitaine, two mechanisms aim to collect, manage, validate and disseminate all the information on biodiversity produced by data producers and particularly the technical partners. The Wildlife Information System (SI Faune) has 8 thousand data and the Observatory of Plant Biodiversity (OBV) of New Aquitaine 3 million data. These atlas biodiversity data can be processed in the form of species presence. The observation effort is heterogeneous in the territory and does not allow a relevant analysis of presence and absence of species. This type of data can still be used in the scientific literature. For example, Brotons et al. (2004) used bird atlas data in Catalonia. According to the authors, presence and absence of species data

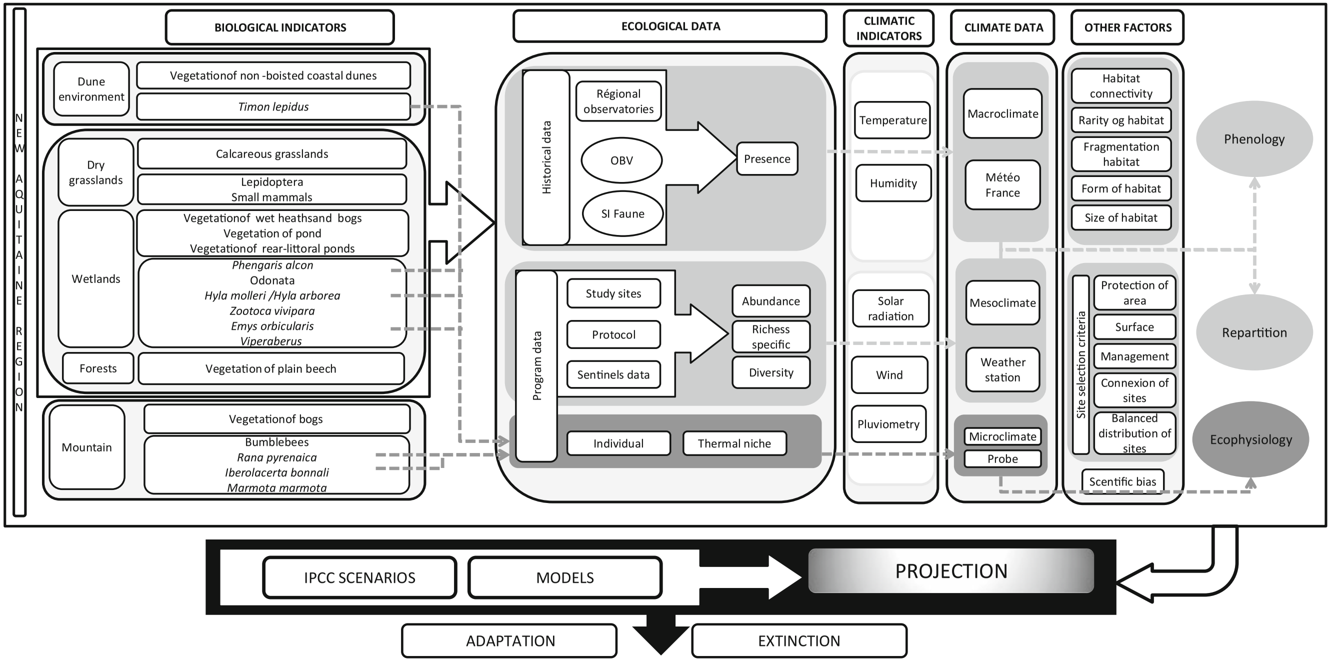

Fig. 5 Overall plan of analysis of the Climate sentinels program. In order to study the effects of climate change on biodiversity at the regional scale, the observation in the field requires sufficient data in order to obtain relevant results. Regional observatories are tools to access a mass of naturalistic observations, validated and distributed throughout the territory. However, these data allow us to access mainly the presence data. The data come from naturalistic observation protocols not yet standardized protocol. At this scale the Météo-France data are used. The abundance data of individuals contain a wealth of important analysis. The combination of this second type of complementary data with that of the presence data ones enriches and validates the models. These data require, in all cases, protocolized monitoring of natural populations in the field. To be linked to climate change, the monitoring of sentinel species is supplemented by spot monitoring of temperature and humidity at each site through a weather station. Ecophysiology can contribute to a global vision of the impacts of climate change on organisms, ecosystems and their evolutionary responses. Species and their life stages have different thermal ranges reflecting specialization in temperature regimes, habitat and lifestyle characteristics. Their temperature limits can be modified by acclimation or evolutionary adaptation to specific limits. Thermal probes are used to mimic the thermal and hydric properties of organisms. The type of climate model adapted to the program is the MDS (Species Distribution Model) integrating all biological, climatic, historical and recent indicators, as well as the scenarios of the Intergovernmental Panel on Climate Change (IPCC)

allow projections by generalized linear models (GLM) more accurate than ecological niche factor analysis (ENFA) using only presence data. Species with less stringent ecological requirements are modelled with less precision than species with lower requirements. Models for large and tolerant species are more sensitive to absence data, suggesting that presence/absence methods may be particularly important in predicting distributions of this species type. It is more difficult to accurately project independent generalist species distributions with the method used (Brotons et al. 2004). In the program, we selected small species, mostly specialists. The presence data are then sufficient for predicting the evolution of these sentinel climate species in the face of climate change.

Protocoled Monitoring Data

The abundance data of individuals and the relative proportions of species allow a wealth of analysis. The combination of this type of complementary data with species incidence or presence-absence data enriches and validates models and the levels of uncertainty for analysing the effects of global changes on biodiversity. Incidence or presence-absence data from species are easier to obtain than abundance data from individuals and relative proportions of species related to number of individuals observed (Howard et al. 2014). These last data require, in all cases, protocoled monitoring of natural populations in the field. Long-term monitoring of natural populations is generally considered as essential. Direct observations should be made over periods of several decades (Bertin 2008). The implementation of protocols for monitoring climate and biological indicators standardized and adapted to the problem of climate change is necessary. As part of this project, monitoring protocols for climate and biological indicators were defined in 2016 (Mallard 2016b).

For each fauna or flora indicator, the sampling plan defines the criteria for the associated study sites. A working hypothesis for the selection of study sites is to rely on a state of conservation of sites limiting, as much as possible, the influence of anthropogenic factors other than climate change, which may often have a greater impact on local biodiversity. In this study, the selection of the sites is thus based on a reference of a state of conservation described as "good".

In a climatic region, the climate varies from place to place; local microclimates change according to altitude and latitude. The climatic conditions are peculiar and result from topography and vegetal cover. The combined action of climatic factors, and especially the temperature-humidity pair, directly affects the distribution of plant and animal species and the development of their populations. Monitoring sentinel species is therefore complemented by spot measurements of temperature and humidity at each site. These two factors are the most representative and most easily measurable climatic conditions of populations at this local scale (Mallard 2016b).

A first field campaign in 2016 allowed the installation of equipment and the testing of protocols. The protocols validated in 2016 are based on methods recognized at national level. Depending on the indicators of the different dune, dry, wet, forested, mountainous environments, the number of monitored sites ranges from 5 to 80. Flora monitoring is carried out once a year per site in 2017 and renewed for 3–6 years. Wildlife indicators are measured annually during the duration of the program with 2–9 surveys per year and per site (Mallard 2016b).

Ecophysiology can contribute to a global vision of the impacts of climate change on organisms, ecosystems and their evolutionary responses (Bozinovic and Pörtner 2015). In this program, the ecophysiological responses of individuals are studied using experimental field devices such as probes and thermocouples placed in biomimetic models to imitate the thermal and hydric properties of organisms (Sinervo et al. 2010).

Projection Modelling

In order to establish an overall analysis of all the data collected, we have identified and analysed existing models on climate change and biodiversity. The method of analysis is the same as the one of the state of the art of the effects of climate change on the different groups of species (Mallard 2016a).

Over the past 20 years, studies on modelling of species distribution and climate change have been very numerous. We have listed and described the computer models used “impact factor” review papers to determine the relevant model(s) for the chosen indicators of the program. We have identified potential gaps in current models and research pathways to obtain predictive maps of species distributions. The models are classified in 4 main categories, from the simplest, like GLM—Generalized Linear Model, to the most complex ones, like Random Forest (RF) or ANN—Artificial Neural Networks (Mallard 2017). The models are used alone or in combination, their results being mostly improved when combined (Leathwick et al. 2006; Watling et al. 2015). In practice, a frequently used model is the Species Models Distribution (SDM). Its approach is flexible and allows to integrate a large number of factors such as fragmentation, dispersion or altitude but also climate scenarios. SDM can be based on three different types of models (empirical, analytical or mathematical, mechanistic) (Guisan and Zimmermann 2000). According to some authors, it is quite accurate and gets good results when compared with other models. However, it also has limitations and has been controversial in some studies.

The uncertainty of the model can result from the initial hypotheses (Dormann et al. 2008). If the questions asked of the models are not sufficiently defined, the results will be biased and will not be acceptable (Elith and Leathwick 2009). Simplified model boundaries describe complex processes, such as models describing future climate conditions or algorithms describing species-environment relationships. The algorithm remains the most important source of uncertainty. The result of the modelling must be interpreted carefully. Models are limited by lack of data, inaccurate data, or missing data (Dormann et al. 2008). In Climate sentinels program, the data used for modelling is largely derived from established protocols, which minimizes prediction errors. Failure to take certain factors into account may influence model results such as altitude (Oke and Thompson 2015), dispersal (Gonçalves et al. 2016) or biotic factors (Singer et al. 2016). A small number of factors will not yield solid results. With too many factors, the model becomes too heavy to run. The predictive maps are then biased and the results no longer make it possible to isolate the climate change factor. This state of affairs has been taken into account in our reflection and integrated into the models applied to the program the essential factors (biological, climatic, spatial or even anthropogenic) in order to obtain reliable and robust results allowing to observe the modifications related specifically to the climate change. The number of factors can also be a barrier to the transferability of the models developed in the program. From one territory to another, even very similar, the factors differ and the results too (Duque-Lazo et al. 2016). The use of direct factors/resources makes the model more generalizable and transferable. In regard to the different scales and varied territories present in the program, it is highly probable that for each indicator the model must be adapted according to the scale, the environment, and the climatic conditions. That is to say that during the data campaign and associated modelling, algorithms have to be adapted to become more efficient according to the species and the spaces concerned. Scale and time transferability is not the only difficulty encountered when transposing a model from one territory to another, extrapolation is also a source of error, especially when models must predict future conditions, particularly because landscapes futures will likely include climate data that will not be similar. Models that are too complex can lead to biased predictions during extrapolation. As a result, predictions can be biased and become useless for guiding decision-making as part of environmental management measures (Bell and Schlaepfer 2016). All of these criticisms are indispensable in the improvement of the model. Naturalists, researchers in the same project can propose improvements, model adjustments to minimize biases.

Even though the SDM is sometimes controversial (Heikkinen et al. 2007; Guo et al. 2015), its remains an option in a modelling approach in the context of species mobility linked to climate change. This model has shown its robustness in predictions (Bell and Schlaepfer 2016). The main criticism was to give biased results when not taking into account a factor or because of an inappropriate use without thinking defined beforehand (Oke and Thompson 2015; Gonçalves et al. 2016; Singer et al. 2016). Nevertheless, over the years, the addition of different factors by the researchers has significantly improved its performance (Bell and Schlaepfer 2016).

The SDM integrates all sentinel biological indicators, climate, historical and recent data, as well as scenarios from the Intergovernmental Panel on Climate Change (IPCC). The RCP (Representation Concentration Pathways) scenarios considered in the program are RCPs 4.5 and 6 which gives a stabilization of greenhouse gas emissions and the RCP 8.5 which remains the most pessimistic scenario and does not provide any reduction of the greenhouse gas emissions, rather an increase in them (GIEC 2013). Not taking into account these scenarios would distort our future predictive maps. Predictive performance and model correlation are evaluated by statistical measures. AUC—Area Under Curve—and TSS—True skill statistic, called also Hanssen Kuipers discriminant, allow to test the predictive performance of the model in terms of presence/absence of species (Watling et al. 2015; Phillips-Mao et al. 2016).

Conclusion

Because of its rapidity and intensity, current climate change is a major (direct or indirect) pressure on biodiversity. The Climate sentinels program contributes and offers an innovative global approach in applied ecology, based on a strong scientific base, to understand the interactions between climate variations and the biodiversity responses. Ongoing work is being done on a regional scale relevant to the implementation of conservation measures: New Aquitaine, west of France. This work is based to clarify short and long-term impacts, negative or positive influence levels, direct, indirect and induced effects on fauna and flora species in various ecosystems. The emergence of sub-branches of ecology related to human activities is relatively recent. The concept of "ecology of climate change" does not exist to our knowledge yet. The study establishing the ecology of climate change is thus rooted in a multidisciplinary approach, at the interface between ecology, climatology and geography, at the interface between research and naturalistic expertise.

Twenty biological monitoring indicators, known as climate sentinels, have been selected and developed from species or groups of species that are among the most sensitive to climate change, and are easy to follow to ensure work at the level of New Aquitaine. This research field is essential to feed data and to use projection models. This requires consistency efforts to set up shared methods, repositories to address, and complete or continue ongoing research. With all the various partners of the program, scientifically standardized climate and biological monitoring materials and protocols were set up, tested and validated in 2016, the first campaign being done in 2017.

The diversity of 5 lowland environments, from littoral to mountain environments are considered on more than two hundred sites which will be followed till 2021. These data are the basis of the projections of future impacts of climate change on biodiversity. The data will feed the transfer of information to stakeholders, driving forces, which is necessary for the development of conservation strategies and the promotion of informed and voluntary environmental policies. The awareness of the actors will be all the more important and accepted that the method and results of research are widely disseminated. Mediation tools are developed and adapted to targeted audiences to disseminate and make available bibliographies, means, methods and results of the program.

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Introducing Spatio-Temporal Conservation Units: Models for Flexible Optimization of Species Persistence Under Climate Change

Diogo Alagador and Jorge Orestes Cerdeira

Abstract Anticipating the effects of climate change on biodiversity and integrating them in planning protocols for the future are fundamental strategies to increase the effectiveness of conservation efforts. With climate change, species require dispersal skills to follow displacements of their suitable climates and therefore, spatial conservation interventions need to consider such dynamics. In general, common planning frameworks identify networks of conservation areas seemed important for species range shifts. However, it is highly unlikely that all the areas in a network present synchronous conservation value. Furthermore, given the continuous (spatial and temporal autocorrelated) nature of threats and ecological processes, the value of each area is largely dependent on the state of the neighboring areas in the recent past. In this study, a family of three models centered on the prioritization (not of single areas but) of temporal chains of areas as conservation units is presented. These models drive the use of financial investments through time in order to maximize the persistence of biodiversity in dynamic environments. Alike the most typical approaches, the here introduced models allow investments to be transferred between areas losing conservation relevancy to the areas that gain relevancy. A fictitious (but plausible) conservation plan for ten mammal species in Iberian Peninsula up to 2080 is used to illustrate the setting-up and outputs of the models. Results evidence that the conservation effectiveness achieved in each model depends on singular spatio-temporal distribution relationships among species and between species and distinct land-uses. Planners should then investigate the sensitivity of their goals to distinct decision-support tools even when driven by similar designs and constraints.

D. Alagador (✉)
Research Center on Biodiversity and Genetic Resources, University of Évora, Casa Cordovil, Rua Joaquim Henrique da Fonseca, 7000-890 Évora, Portugal
e-mail: alagador@uevora.pt

J. O. Cerdeira
Department of Mathematics, Faculty of Sciences and Technology, NOVA University of Lisbon, 2829-516 Caparica, Portugal
e-mail: jo.cerdeira@fct.unl.pt

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Introduction

Biodiversity conservation typically runs under constrained budgets and with overarching aspirations. At present time, growing impacts of anthropogenic activities on habitats and species have been attested (Venter et al. 2016). These make protected areas (PA) attractive instruments to counteract these negative effects. Planned to set aside biodiversity from local impingent stressors, the typical way PA are established (as territories of perpetual protection) is not ingenious enough to counter the effects of pervasive and dynamic threats, as the ones typically arising from climate change (Hannah and Salm 2003). Under this context, novel-informed decisions are required in order to make long-term conservation (characterized by complex, non-linear processes) effective. A paradigm shift is needed in order to align PA establishment with the dynamics of climate such that biodiversity responses are anticipated and integrated within conservation models (Araújo et al. 2011a; Scott and Lemieux 2005; Dodd et al. 2010).

As the spatial patterns of climate change with time, species rearrange their distributional ranges in order to keep track of their suitable climatic conditions (Garcia et al. 2014). Species that were adequately represented in PA may lose protection. Species that were once poorly covered in PA may gain protection. New species, once not part of a given region, may appear while other species may leave (Araújo et al. 2004). Under such a melting pot of responses, planners need to control out which species need to be represented and to what levels those representations should be maintained into the future within PA, to make them persist.

In the last two decades several PA selection models have been proposed. Broadly, these models followed two general Operations Research problems (Williams and ReVelle 1997): the minimum set cover and the maximal coverage. In the minimum set cover (*minCost*), PA are identified in order to cover a given representation level of each biodiversity feature in the minimum area (or with the minimum financial investment). In the maximal coverage model (*maxCoverage*), PA selection is made to maximize the number of biodiversity features adequately represented, with a fixed budget to spend on area protection (see Table 1 for a comprehensive characterization of these models). These models have mostly been used with a static overview on biodiversity distribution and conservation area cost, thus retrieving PA maps unlikely to counter-back the negative consequences of climate change. A smaller number of studies used these same problems integrating time-varying biodiversity distributions in decisions protocols (for a review see, Alagador et al. 2016). Capable to deliver solutions for PA establishment with regard to climate change effects on species, the problems formulated therein were not dedicatedly developed, nor are fully optimized, to handle environmental dynamics. For example, solution maps built to anticipate climate change effects over several decades into the future, do not give information on the timing each spatial conservation unit is likely to gain (or to lose) relevancy to enter into (or to be released from) an effective PA network. Also, because solution maps do not present a time-component, it is not possible to identify a conservation unit that may functionally replace a given highly disturbed conservation unit.

Table 1 The minimum set cover and the maximal covering problems for PA selection

	Minimum set cover (*minCost*)	Maximal covering (*maxCoverage*)
Objective	Minimize total solution area/cost	Maximize total number of species adequately represented (i.e. over a predefined target)
Constraints	Each feature is represented over a predefined target (e.g. range area, number of populations, number of individuals, number of alleles, etc.)	A fixed budget limiting the area to select
Data needed	For each spatial conservation unit data on features (e.g. occurrence, number of populations, number of individuals, presence of alleles, etc.) and on conservation costs	

This paper introduces a new viewpoint on conservation units when considering climate-change-concerned area selection models. Differently to the typical spatial prioritization frameworks, the study here presented optimizes the use of financial resources in a dynamic manner, allowing the investments made in areas that lose conservation relevancy as climate changes to be reallocated to areas that present the largest cost-effectiveness for most of the concerned species. Specifically, the paper adjusts area selection models settled around the *minCost* and *maxCoverage* models to enable climate change effects to be addressed in conservation plans. A third area selection model that complements the two previous ones is also introduced. Differences among PA solutions retrieved by these three climate-change-concerned area selection models are discussed using a plausible conservation plan for ten mammal species in Iberian Peninsula up to 2080 as an illustrative example.

A New Conservation Unit: The Climate-Change Concerned Conservation Corridor

While typical conservation decisions are framed around spatial units of land, when time comes into play as a new dimension on which conservation decisions have to be made, spatio-temporal conservation units gain relevancy. If a conservation plan is to be implemented, and distribution data exist $\{o_{s,j}^{t0}, o_{s,j}^{t1}, \ldots, o_{s,j}^{tN}\}$ for each species s of a set S of species among every spatial unit j (i.e. grid cell) of a map J for a sequence of periods of time $\{t_0, t_1, \ldots, t_N\}$, a climate change concerned conservation corridor (spatio-temporal corridor; herein, st-corridor to simplify) is a set of N spatial units, one unit defined for each period of time, on which the persistence of a species is evaluated.

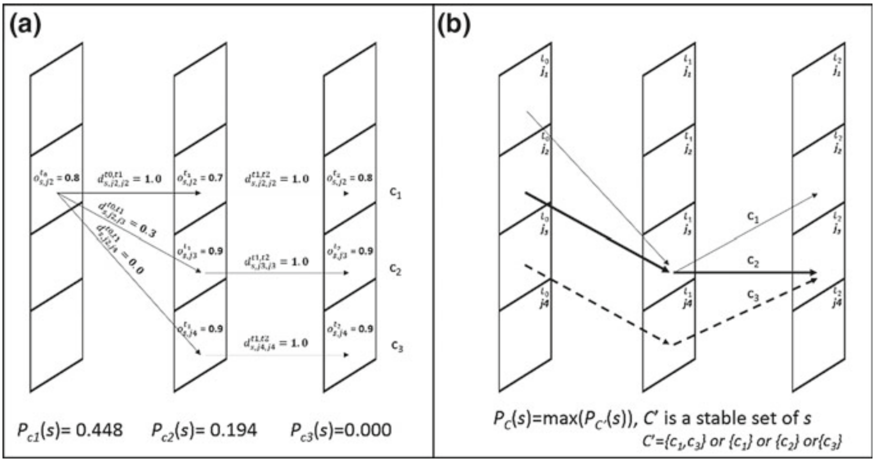

Fig. 1 Schematic representation of st-corridors. In **a** persistence scores are associated to three st-corridors (c_1, c_2 and c_3) using data on probability of occurrence ($o_\cdot^\cdot$) and probability of successful dispersal ($d_\cdot^\cdot$). In **b** the evaluation of a non-independent set of corridors is illustrated. The st-corridors c_1 and c_2 use j_3 at t_1 and c_2 and c_3 use j_3 at t_2. These are therefore non-independent. Contrarily, although made by the spatial unit, j_3, c_1 and c_3 use it at different periods of time periods and are therefore independent. The maximum persistence additively associated to all possible stable (independent) sets of st-corridors measures the persistence of a species s in the final solution

In accordance to probability theory, the probability of an entity to persist within a system evaluated at discrete-times (assuming independence) is the product of the probabilities of the entity to occur in each period of time with the probabilities of the entity to pass from one time to another. With o_{sj}^{ti} as the probability of a species s to occur in spatial unit j at time t_i (data typically retrieved through habitat suitability models, Araújo and Guisan 2006), then the probability of a species to persist in a st-corridor, c made by $\{j_0, j_1, ..., j_N\}$ is:

$$P_c(s) = o_{s,j_0}^{t_0} \times d_{s,j_0,j_1}^{t_0,t_1} \times \cdots \times d_{s,j_{N-1},j_N}^{t_{N-1},t_N} \times o_{s,j_N}^{t_N} \tag{1}$$

where $d_{s,j_n,j_{n+1}}^{t_n,t_{n+1}}$ is the probability of a species s to successfully disperse from j_n to j_{n+1} at $[t_n;t_{n+1}]$ time-interval. Given that species-specific dispersal rates are highly variable in space, accurate data are hardly available to be used at specific contexts for several species. Dispersal kernels are therefore used as general models to infer how dispersal success varies with dispersal distance. In general, the largest the dispersal distance the lowest the probability of success. In limit, if a species does not disperse then $d_{s,j,i}^{t_n,t_{n+1}} = 0$, for $j \neq i$ and $d_{s,j,j}^{t_n,t_{n+1}} = 1$. For distances larger than the distance a species is able to disperse in a given time-period, $dmax_s$, (i.e. $dist(j_n, j_{n+1}) > dmax_s$), then $d_{s,j_n,j_{n+1}}^{t_n,t_{n+1}} = 0$. An illustrative example on how persistence scores are evaluated is outlined in Fig. 1a.

The selection of PA supporting the persistence of species along time (from t_0 to t_N), passes by the identification of a given number of st-corridors for each of the species. However, in order to be fully effective, the st-corridors identified for each species should form a *stable set* in the sense that, no two corridors may use the same spatial unit in the same time-period (Fig. 1b exemplifies the evaluation of total species persistence in a non-stable set of st-corridors). In this way negative contagious effects that may occur in each spatial-unit in a certain period of time are not spread into other st-corridors, thus promoting redundancy in the set of st-corridors of each species.

With st-corridors, the effect of a disturbance acting in a specific location and timing may be measured in every other spatial units and time periods (see Fig. 2, for an illustration of a portfolio of disturbing factors acting at distinct spatial units and time-periods).

Persistence as Conservation Targets

The ultimate goal of conservation is to promote the persistence of biodiversity features at long-term. However, the evaluation of persistence is hardly made anticipatively, as by nature implies time to collect and analyze data. Therefore, several general rules have been used to estimate persistence and therefore to define conservation targets in area selection models. For example, amount area, number of species, number of populations and allele frequency within PA have been considered as targets to achieve in final solutions (Neel and Cummings 2003; Pressey et al. 2003). In area selection models, like the ones here introduced, the estimation of persistence may be upgraded adding the temporal dimension, as mentioned in Eq. 1 (Alagador and Cerdeira 2017). In the following section, the difficulties associated with the definition of persistence targets will be discussed and proposal for their definition made.

Area Scheduling Models: Area Selection Through Time

Settled as conservation units, st-corridors may be used with distinct area selection models developed to handle the spatially-dynamic impacts of climate change impinging biodiversity. Instead of spatial units, these climate change concerned models operate with the evaluation and selection of st-corridors for maximizing (or minimizing) some benefit (or cost) function.

A proximate version of the *minCost* model may be built using st-corridors as selection units (K-$minCost^{st}$). Like *minCost*, the objective in K-$minCost^{st}$ is the identification of a solution of minimum cost (but now made by st-corridors) in which the established persistence targets are fulfilled. There is, however, a detail that needs to be highlighted when quantifying solution cost using st-corridors instead of spatial units. Unlike the static models, for which solution cost is made by adding up the costs associated with the selected spatial units, solution cost in st-corridor-based models

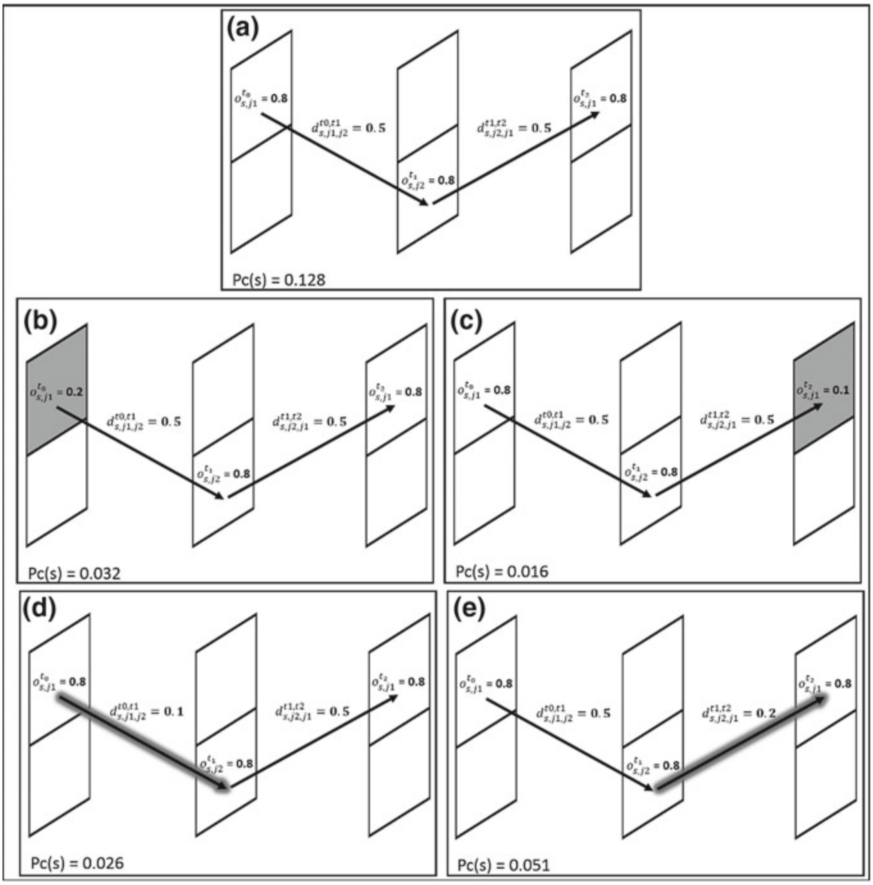

Fig. 2 The multiple effects of disturbing factors over the persistence of a species in st-corridors. **a** represents the persistence of a species in a st-corridor within a referential landscape; **b** and **c** the effect of a disturbance at the local level, changing species suitability in time t_0 or time t_2, respectively; **d** and **e** the effect of a disturbance on the dispersal capacity of a species, either acting in the $[t_0;t_1]$ or in the $[t_1;t_2]$ time intervals, respectively

are not additively taken from the costs of the selected st-corridors. Instead, when a solution is made by st-corridors using the same spatial unit for the same time-period, the cost associated with the use of that confluence area is only counted once. This makes unnecessary the estimation of cost for each st-corridors, given that, in these models, the cost is evaluated at the level of the spatial unit.

Driven by persistence targets, the here introduced models are highly exposed to unfeasibility (i.e. no solution exists attaining all the established requisites). Given that persistence targets have not a clear direct relationship with a spatial explicit index, if they are established too high (even if for a single species) no feasible solution may exist (Alagador and Cerdeira 2017). A new parameter K, defining the minimum number of species that need have their targets fulfilled in final solutions, may thus allow the problem to be relaxed, and the "faulty species" to be identified.

Similarly, the *maxCoverage* model may be easily transformed in order to accommodate climate change concerns into conservation planning (*B-maxCoverage*st). Like *maxCoverage*, in this st-corridor-based version, the objective is to maximize the number of species with targets fulfilled when the budget (B) for area selection across time is limited. In this problem, the use of budget may be established in two modes: (a) a unique budget to be wasted along the analyzed horizon of time, or (b) a stricter version, in which budgets are defined (and used) in each time-period of analysis.

As with their static analogs, the *K-minCost*st and the *B-maxCoverage*st models present a kind of dual relationship. That is, being mC^K, the cost of an optimal solution of *K-minCost*st, making $B = mC^K$ the objective value of *B-maxCoverage*st is K. The choice of the model to run thus depends largely on the specific question planners need to answer and also on complex issues associated with problem-solving. The balance between the number of species in analysis and the number of spatial units across time determines the time needed to get a full optimal solution. In the most cases, spatial units largely overweight number of species making solutions for the *K-minCost*st easier to get.

In the above models, if final solutions only partially achieve the target for a species, no benefit value is accounted at all for that species. That is the benefit that the st-corridors in final solution provide to species is measured with an all-or-nothing function. To avoid this lack of evaluation, a model may be built accounting for any investment made for a species, even if it does not suffice to fully achieve the target. In the model—*BK-minShortfall*st—the objective is to minimize the sum of target-shortfalls among species, within the selected st-corridors using the budget B, and such that at least K species have their targets fulfilled.

Given the large number of viable st-corridors that may be defined for each species (depending on the number of spatial units where species occurs in t_0 and on the species dispersal ability) a pool of st-corridors presenting the largest persistence scores may be used to limit the range of variables and therefore to reduce problem size.

An Illustrative Example

The Iberian Peninsula is a biodiversity-rich region with a large area under a Mediterranean climate regime. Bordered by the Atlantic at the southern, western and northern margins and by the Pyrenees at the eastern margin, is a region in which the large expected climate change will have tremendous impacts on biodiversity. Moreover, given the pervasiveness of human land-use (dominated by agriculture, forestry, cattle-raising and urban sprawl), species range shifts within the region are highly restrained. To illustrate the outputs from the climate change concerned area selection models, a set of ten mammal species listed in the Portuguese and Spanish red-lists, are used. Data on the predicted climatic suitability of each species, s, from present time to

2080, t_N, ($o^{t_N}_{s,J}$) were obtained for all the region, J, using bioclimatic models, which statistically relate a series of climatic predictors with species occurrence data to infer the favored climatic conditions for a species to occur (Araújo and Guisan 2006). The models were then projected into the future, using data on future climate tendencies averaged across 30 yr. time-periods, centered in 2020, 2050 and 2080 (and assuming a plausible, extreme green-gas-house emission scenario, A1FI, IPCC, 2007). Data were obtained for 10 km × 10 km spatial units spanning the region (for a detailed description of the modelling protocol see, Araújo et al. 2011a). Species' suitability data for present-time was filtered such that the spatial units where species were not recorded were considered unsuitable, therefore reducing commission errors. Dispersal data for each species was obtained assuming a dispersal kernel that relates the probability of successful dispersal from a source, j_{n-1} to a target point, j_n (in 30 yr time) with the geographic distance between those points $dist(j_{n-1}, j_n)$ and the maximum dispersal distance a species presents for that time-interval ($dmax_s$):

$$d^{t_{n-1},t_n}_{s,j_{n-1},j_n} = exp^{-\alpha_s.dist(j_{n-1},j_n)/dmax_s} \tag{2}$$

where α_s is a species specific parameter. On the absence of accurate specific data for the species in analysis the same value, $\alpha_s = 2.9957$, was settled for all the species.

For the prescription of species persistence targets, climate (and land-use) of future time-periods were considered as replicates of present-time climate and land-use (i.e. no-change scenario). The 500 st-corridors presenting the largest persistence scores for each species were selected and the *BK-minShortfall*st was run using $B = \infty$ (i.e. a large number), $K = 0$, and with (transient) targets for the ten species set to ∞ (i.e. a large number). Because in this analysis, an infinite B does not limit the final solution, the cost to conserve each spatial unit was arbitrarily settled to one (for all time-periods).

The values $maxPers_s$ obtained from the analysis above were then rescaled, such the persistence targets to be defined (tg_s) reflect the perceived importance of conservation for species. Therefore, targets for the species presenting the smallest $maxPers_s$ scores should represent a larger fraction of $maxPers_s$ when compared with the targets for the species with the largest $maxPers_s$:

$$tg_s = \begin{cases} maxPers_s & \text{if } maxPers_s \le 1 \\ \ln(maxPers_s) + 1 & \text{if } 1 < maxPers_s \le 10 \\ \ln(10) + 1 = 3.30 & \text{if } maxPers_s > 10 \end{cases} \tag{3}$$

Less demanding target analyses were also made with targets $tg'_s = tg_s/2$. Table 2 summarizes the parameters used in the illustrative the case-study.

Table 2 The species in analysis; their Red List Book (RL) threat status in Portugal (PT) and Spain (SP); the maximum dispersal distance ($dmax_s$), the maximum persistence obtained in a non-climate change scenario ($maxPers_s$) and the target defined for the most target demanding assessments (tg_s)

Species name	Abbrev	RL Status		$dmax_s$ (km/30 yr)	$maxPers_s$	tg_s
		PT	SP			
Galemys pyrenaicus	*Gpy*	VU	VU	20	4.07	2.40
Mustela erminea	*Mer*	DD	DD	10	1.86	1.62
Mustela lutreola	*Mlu*	NT	EN	10	0.03	0.03
Oryctolagus cuniculus	*Ocu*	NT	VU	65	88.04	3.30
Arvicola sapidus	*Asa*	NT	VU	31	34.60	3.30
Microtus cabrerae[a]	*Mca*	VU	VU	115	0.21	0.21
Canis lupus	*Clu*	EN	NT	160	3.76	2.32
Ursus arctos	*Uar*	EX	CR	200	0.08	0.08
Felis sylvestris	*Fsy*	VU	NT	200	21.23	3.30
Capra pyrenaica	*Cpy*	CR	NT	200	0.29	0.29

EX Extinct; *CE* Critically endangered; *EN* Endangered; *VU* Vulnerable; *NT* Near threatened; *DD* Data deficient; [a]endemic of Iberian Peninsula

Data on the cost to assign to each spatial unit for conservation were derived from land-use data for present-time and the time-periods aligned with species data (i.e. 2020, 2050, 2080). For each spatial unit, j, in each time-period, t, the fraction cover with agriculture ($f_j^{t,agr}$), pasture ($f_j^{t,past}$), forests ($f_j^{t,for}$) and urban lands ($f_j^{t,urb}$) was measured and the cost to use each spatial unit in a given time period (Alagador and Cerdeira 2018) settle as:

$$cost_j^t = 1 + f_j^{t,agr} + f_j^{t,past} + f_j^{t,for} + f_j^{t,urb} \qquad (4)$$

The K-$minCost^{st}$ model was run using $K \in \{1, 2, \ldots, 10\}$. The solution costs obtained either with the most and the less demanding target-settings (for each K value, with mC^K retrieving feasible solutions) were used as referential values to define a set of B values to use in the other two models ($\bar{B}$). Adding to those values, each interval [mC^K,mC^{K+1}], was portioned in five equal-sized sets and their inner limits defined four more B values to use (with $K < K^{max}$ and K^{max} the maximum K retrieving a feasible K-$minCost^{st}$ solution). Four B values were also established below mC^1 (0.90. mC^1; 0.925. mC^1, 0.95. $mC^1$and 0.975. mC^1) and above mC^{Kmax}

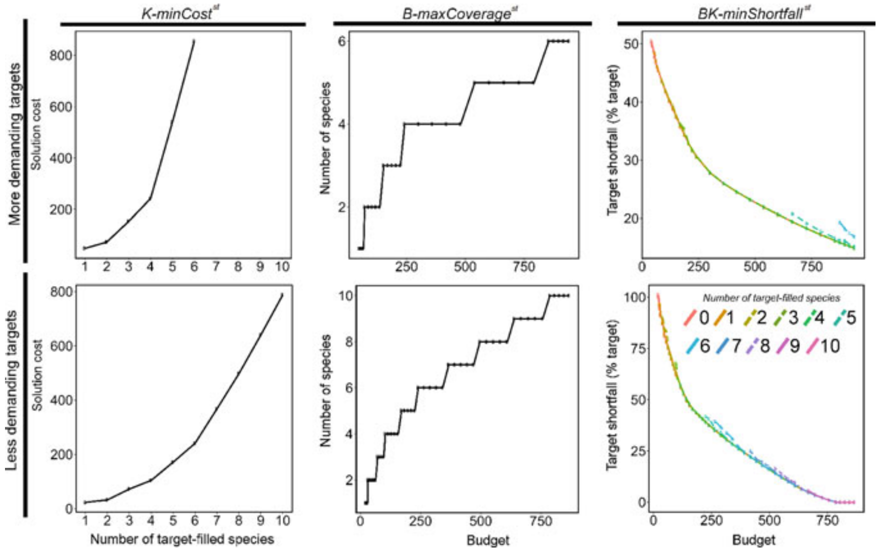

Fig. 3 Performance of the three introduced area selection models for the protection of the ten analyzed species in Iberian Peninsula from present-time to 2080 under the A1FI climate change scenario. The models were ran varying *K* (number of target-filled species) and *B* (budget) for a more demanding and a less demanding target-setting

(1.025. mC^{Kmax}, 1.05. mC^{Kmax}, 1.075. mC^{Kmax} and 1.1. mC^{Kmax}), thus making 9 + 5.($K^{max}-1$) *B* values in $\bar{B}$.

The *B-maxCoverage*st and *BK-minShortfall*st models were run using $\bar{B}$ and $K \in \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$.

Results

With the most demanding target setting, only six species achieved their persistence targets (see Fig. 3). With the less demanding scenario, all the ten species achieved their targets. Solution cost varied exponentially as *K* increased, but this increase was more pronounced with the most demanding target setting. For $K = 6$, the solution cost in this scenario was four times larger than the cost obtained with the less demanding targets. The patterns obtained with the *K-minCost*st model translated into the *B-maxCoverage*st as a step function, in which the gain of attaining a new target-filled species was much costlier after the targets of several other species have been fulfilled.

The *BK-minShortfall*st results showed that with the lowest budgets, *B*, and for $K \in \{0, 1, 2\}$ the less demanding target setting generated solution with larger relative target-shortfalls when compared with the more demanding target solutions. However, for $K \in \{5, 6\}$ (under the same *B*) the less demanding target setting generated solutions with smaller target-shortfalls. Also, increases in *K* did not generate loss of solution effectiveness.

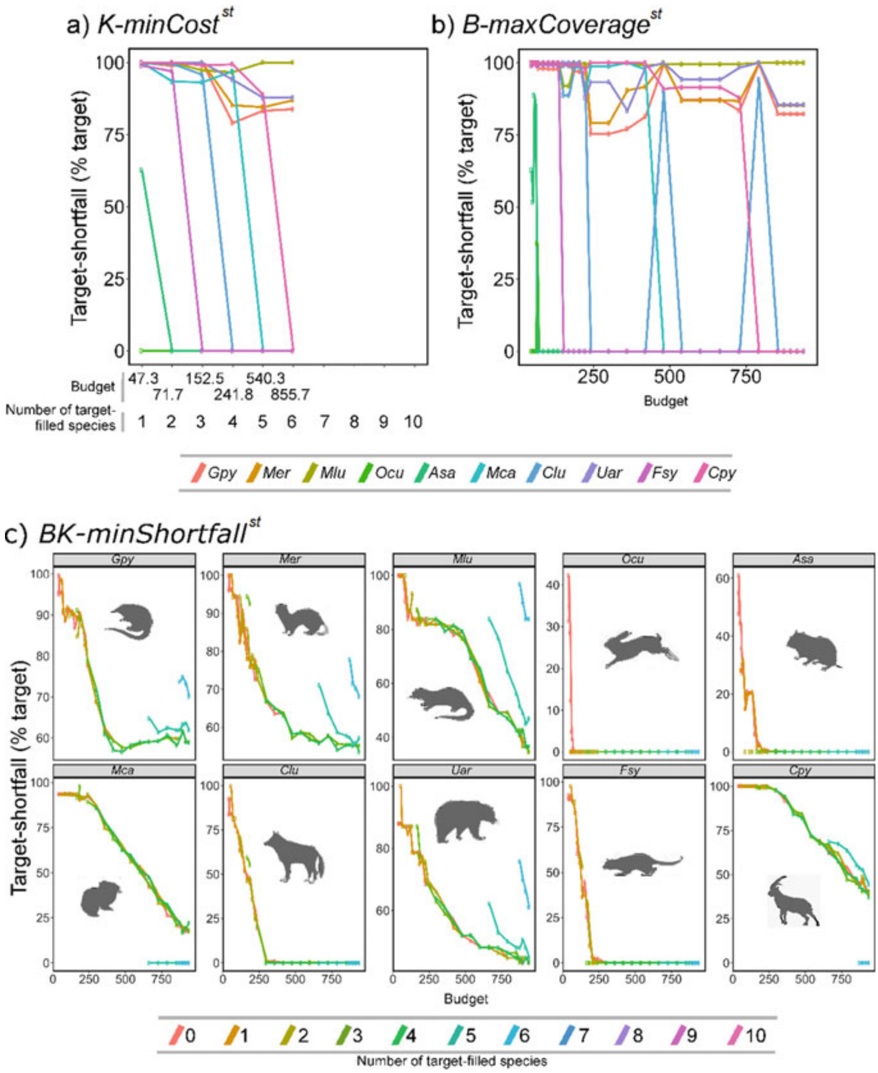

Fig. 4 Shortfall to persistence targets (as a percentage of targets) obtained for each species in solutions of varying cost (budget) using: **a** *K-minCost*st, **b** *B-maxCoverage*st, and **c** *BK-minShortfall*st models. Plots refer to the most demanding persistence targets assessed. ***Gpy***: *Galemys pyrenaicus*; ***Mer***: *Mustela erminea*; ***Mlu***: *Mustela lutreola*; ***Ocu***: *Oryctolagus cuniculus*; ***Asa***: *Arvicola sapidus*; ***Mca***: *Microtus cabrerae*; ***Clu***: *Canis lupus*; ***Uar***: *Ursus arctos*; ***Fsy***: *Felis sylvestris*; ***Cpy***: *Capra pyrenaica*

The effectiveness to protect the distinct species differed significantly with the model used and with *K* and *B* values (see Fig. 4 for a full evaluation of the persistence expectancies of each of the ten analyzed species under the full parameterization space experimented). The accrue of target-filled species in *K-minCost*st followed a sequential-cumulative pattern with *Ocu, Asa, Fsy, Clu, Mca* and *Cpy* being added to the set of target-filled species respectively. This nested pattern of target-filled species was not reproduced in the *B-maxCoverage*st. For some budgets decisions on which of two species to cover adequately have to be made leading to shifts on the set of target-filled species.

The species-specific curves representing solutions from *BK-minShortfall*st permit to distinguish the species requiring less financial resources to meet their persistence targets (e.g. *Ocu, Asa, Fsy*) from the species which (e.g. *Mlu, Mca* and *Cpy*). For $K \in \{0, 1, 2, 3, 4\}$ the increased protection of *Mer* and *Uar* conflicted with the protection of *Gpy*, thus making the target-shortfall of *Gpy* to increase as *B* increased 500 forward.

Fig. 5 presents an overview of cost-effectiveness of spatial units making st-corridors in Iberian Peninsula along time using the three proposed models. Here, the six *K-minCost*st solutions presented higher stability when compared with the solutions retrieved by the two other models (Fig. 5). The 54 solutions obtained with *B-maxCoverage*st delivered a homogeneous map of number of species benefiting from the selection of spatial units with time. Finally, *BK-minShortfall*st solutions presented a large variation in the species favored by the prioritized areas. Most of the spatial units supported two to three species, but in some regions (NW and NE of Iberian Peninsula) spatial units contributed for the conservation of six to seven species within all the time-periods assessed.

Discussion

This study introduces a novel concept in conservation planning (the climate change concerned conservation corridor, st-corridor) that defines a flexible conservation unit to be used when the effects of dynamic processes over multiple species (as the ones generated from climate change) need to be anticipated. Using st-corridors as conservation units in distinct area selection models, planners are able to define a schedule for the uptake (or release) of areas to (from) the side of conservation. When a spatial unit is expected to lose conservation value to other spatial unit(s), it may be released from conservation focus and the investments here saved are transferred to spatial units predicted to retrieve larger conservation benefits. In this way, PA selection surpasses the typical greedy protocols, under which areas are accumulated as time passes, and is converted to a flexible framework that still needs to accommodate to the impacts of the most pervasive socio-economic activities, but that requires less area to retrieve the same or even larger conservation benefits (Fuller et al. 2010).

With the time dimension at play, the most natural way to evaluate the effectiveness of st-corridors is through a quantitative evaluation of species persistence reflecting the vulnerability of species to climate change (or other threats under analysis) and that, depending on data availability and spatial scale, may present distinct structures (Williams et al. 2008). The biogeographical scale of the study-case here used, per-

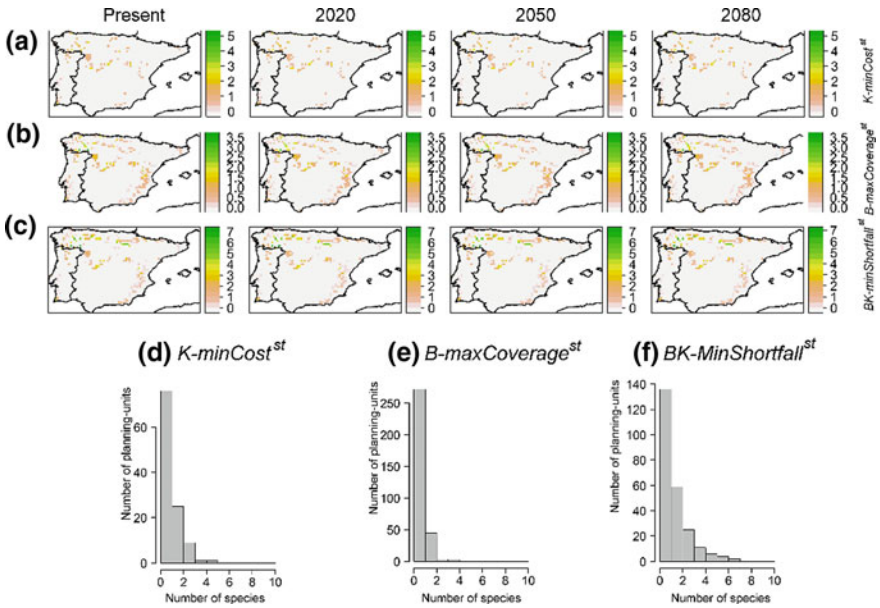

Fig. 5 The mean number of species protected by each spatial unit in each time period obtained among several solutions made by varying K and B, in **a** *K-minCost*st, **b** *B-maxCoverage*st, and **c** *BK-minShortfall*st models using the most demanding persistence targets. Histograms represent the number of spatial units protecting, in average, a given number of species for solutions generated with: **d** *K-minCost*st, **e** *B-maxCoverage*st, and **f** *BK-minShortfall*st models

mitted species persistence scores to be assessed using broad-scale evaluations of climate suitability (i.e. exposure level) and species dispersal abilities (i.e. species sensitivity) through time. From the side of exposure, the effects of micro-habitats and topographic buffering may be integrated for a measure of climate suitability (Potter et al. 2013; Lenoir et al. 2017). The synergistic effects of climate with other factors may also be important to be evaluated. For example, the effects of new occurring species, of excluded species and new species interrelationships (Araújo et al. 2011b), and the occurrence of new threats (like new uses of land) may be integrated into this local suitability score. From the side of sensitivity, genetic, phylogenetic and behavioral plasticity are factors that leverage species' adaptive capacity at the local scale (Shoo et al. 2013). Besides dispersal, other sensitivity indicators as life history traits (e.g. reproductive rates, life-span, metabolic rates), population dynamics (extinct-colonization events under a meta-population structure) and abundance data may also aid to get a more integrative picture of the likely species persistence within the analyzed spatio-temporal system (Hampe and Petit 2005). By acting anticipatively to the effects of climate change over time, the here proposed framework is largely dependent on predictive tools that naturally incorporate uncertainties. Some uncertainties may be quantified and controlled within the final solutions such that robust assessments are made. Measures on the effects of assuming distinct climate scenarios, distinct bioclimatic model types (Araújo and New 2007) and on the likely variability of spatial unit cost (Salomon et al. 2013) may allow an uncertainty layer to be produced. By merging uncertainty and cost, final solutions will tend to give higher priority to the less costly spatial units with the more stable estimations on local suitability (Lemes and Loyola 2013).

While flexible to be used in some particular cases, the models here presented suffer from general caveats. As stated above, although in theory the models here presented may incorporate a portfolio of threats acting at the local suitability and dispersal capabilities of species, the models are mostly appropriate to handle climate change. The st-corridors selected are areas that should be given full consideration as pathways enabling species natural adaptation through time. Given that the states of areas (for the different species) are not dependent on the history of previous decisions (and interventions) either locally on in neighboring areas, testing the effect of changing land-use practices in order to mitigate threats for single or various species should be carried out using pure dynamic implementations of area prioritization models. Given that these effects are stochastic by nature, a large number of potential system states needs to be evaluated which implies greater complexity and new quality-heuristic methods to be developed (Sheldon et al. 2010).

In the models here described, there is the possibility to save investments with reallocation of financial efforts from the areas that lose conservation effectiveness towards the areas whose cost-effectiveness compensate such losses. In practice, more than a redirection of investments, real-world land-markets allow new financial resources to be generated from the released areas. Interest rates, selling or renting contracts may provide new profits for conservation agencies. With the anticipative models here introduced these imbricate economic details may be approximated in advance by informing the cost of intervene in spatial units with possible financial revenues associated to the release of area from conservation focus.

Identically to the example here presented, it is very likely that, faced with the same effectiveness requirements (i.e. K values) and with the same financial resources to invest in conservation (B values), planners will be confronted with distinct solutions when using different area selection models. Importantly, planners need to state their goals clearly; to formulate an adequate optimization protocol (using either a minimum cost or maximum benefit scheme), and to test the sensitivity of their models to parameter variability. This is a process that goes well beyond a few maps of priority areas. Ideally, it should involve a wide array of stakeholders such that intangible variables are considered (Knight et al. 2010). The models here introduced are not prescriptive and may be adopted as support tools to optimally anticipate the wide-ranging effects of climate change on biodiversity and ecosystem services.

Conclusions and Future Prospects

This study introduces the st-corridor as a new conservation unit that has relevancy in anticipative conservation plans, as it allows to find well delimited pathways of species persistence into the future while also identifying the timing spatial units gain relevancy to support species range adaptations as a response to changing climates. These conservation units may be integrated in distinct assignment problems running with distinct goals and constraints and, therefore, have potential to assist stakeholders and decision makers in testing different attitudes towards climate-change-concerned conservation planning. In the future, these models may be implemented in real conservation frameworks looking to resolve the broad question driving conservation planners and policy-makers: where, when and how to use conservation resources in order to make species to persist the increasing challenges from climate change.

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The Impact of Climate Change and Variability on Wild Terrestrial Animals in Selected Rural Coastal Regions of Kenya

Bertha Othoche

Abstract Climate change has become a household term in the North and South coastal region of Kenya. The ever increasing temperature conditions and erratic rains have raised concerns among local communities in the region. The changing climatic conditions has affected both man and animal in almost equal measure. Specifically, migration and disappearance of terrestrial animals have been observed. Climate change and biodiversity and specifically terrestrial animals are interrelated. Climate change affects water and pasture which are the lifeblood to terrestrial animals. These animals need water for transport of nutrients and other metabolic processes. They need pasture to acquire nutritional components and for growth and development. Any adverse change on climate therefore affects the animals directly. This paper presents an assessment of the impact of climate change on terrestrial animals. The specific objectives of the paper include: to assess the changing weather and climatic conditions; to document climate change impacts on terrestrial animals, and to explore the strategies put in place by stakeholders to address the problems. The study adopts a descriptive approach including the use of ten local community leaders and conservation agents as key informants to obtain thematic data on terrestrial animals in the selected areas. Four focus group discussions were organized each with ten local community members to give additional information on climate change and terrestrial animals. Data was analyzed using descriptive statistics and presented graphically in line with the emerging themes. The study generated knowledge and valuable information to global conservation agents, national governments, policy makers and the academia on climate change and biodiversity and specifically terrestrial animals.

B. Othoche (✉)
School of Environmental and Earth Sciences, Pwani University, P.O. Box 195, Kilifi 80108, Kenya
e-mail: b.othoche@pu.ac.ke

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Introduction: Climate Change and Biodiversity

Climate change and weather variability have been observed globally in the recent past. Climate change is the significant and long lasting change in the statistical distribution of weather patterns over periods ranging from a decade to millions of years (Blast 2010). Climatologists have identified upward trends in global temperatures and now estimate an unprecedented rise of 2.0 °C by the year 2100 (Partz et al. 1996). The changing climatic conditions have affected the quality of both terrestrial and ocean biodiversity in different ecosystems.

Biodiversity refers to the variety of life on earth measured at genetic, species and ecosystem levels (Benn 2010). Under favorable conditions, biodiversity flourish and becomes healthy and more productive. The distribution of biodiversity across the globe is influenced by physical and anthropogenic factors. Latitudinal gradients in species diversity has been observed (Field et al. 2009; Young 2003; Tittensor et al. 2010; Myers et al. 2000; Gaston 2000). Generally, biodiversity is in great abundance in the equatorial and tropical areas than it is in the temperate and polar regions. Specifically, terrestrial biodiversity tends to be abundant in the tropical areas while marine biodiversity is abundant along the coastal regions. This is due to warm temperatures and abundance of rainfall in the tropical and equatorial regions (Field et al. 2009). The tropical forests for example cover less than 10% of the earth's surface but contain 90% of the world's species. In general, biodiversity hot spots occur in favorable environments in relation to latitudinal changes (McPeek and Brown 2007; Peters 2013; Robosky 2009). Terrestrial biodiversity plays an important role in the life of man and other animals in general. Indeed, biodiversity offers services and products that sustain ecosystems.

The services offered by biodiversity can be categorised as provisional, regulatory and cultural services. Provisional services involve the production of renewable resources such as food, wood, and fresh water. Regulatory services include those that regulate climate and weather patterns and disease and pest control. Cultural services represent human value and enjoyment and includes cultural heritage, landscape aesthetics, outdoor recreation and spiritual significance (Cardinale et al. 2012; Wright and Bernard 2002; Daniel 2012).

For biodiversity and specifically terrestrial biodiversity to flourish in an area, there should be adequate supply of water. Climate change affects continuous supply of water from direct precipitation (Adams and Dannele 2008). This in turn affects water sources that rely on precipitation. Examples of sources of water that rely on precipitation directly and indirectly include rivers, water pans and boreholes. These water sources are sustained by the hydrological cycle which dictates the amount of water that eventually reaches the earth's surface and remains available for plants. From plants the feeding chains are sustained and therefore existence of ecosystems guaranteed. Sustainable water supply is no longer guaranteed in most parts of the world. This problem has been aggravated by the changing weather and climatic patterns (Bates et al. 2008; Parmesan and Yohe 2003; UNESCO 2003). In the study area rainfall patterns have been erratic for most part of the last decade thereby affecting water supply. Rivers and streams have turned into seasonal channels and some have dried out completely leaving behind sand and gravel during the dry season. Water pans have also dried up and borehole water volume reduced.

Climate change has impacted on biodiversity in different ecosystems worldwide. Both aquatic and terrestrial ecosystems have been affected in one way or the other. More so, climate change has impacted on terrestrial animals specifically (Sahney et al. 2010). It has been established that every organism has a unique set of preferences that enables it to establish its own niche with specific environmental conditions. Each niche has specific conditions that enables the organism to survive. The environmental conditions associated with each niche where each organism survives include climate, soil conditions, competition, latitude, among others. Any alteration of an animal's niche especially when climatic conditions change will definitely affect the wellbeing of the specific animals. Climate change therefore is a major factor to consider when investigating biodiversity and sustainable environmental conditions.

Climate change might result in low productivity in the terrestrial animal ecosystems, poor health of animals, migration and disappearance of the animals as well as extinction of the same animals where adverse conditions spread over a long period of time (Pimm et al. 2014; Rustard 2008; Pearson and Dawson 2005). In the study area, manifestations of climate change have been established. This is in the form of prolonged droughts, ever increasing temperatures and erratic rains (Makenzi et al. 2013). Animals have adversely been affected due to prolonged droughts and inadequate pasture in the midst of erratic rains. It is with this in mind that this paper investigates the impact of climate change on terrestrial animals in the North and South coastal region of Kenya.

The Study Objectives

The specific objectives of the study included: to assess the changing weather and climatic conditions; to document climate change impacts on terrestrial animals, and to explore the strategies put in place by stakeholders to address the problems.

The Rationale of the Paper

Climate change and biodiversity conservation are global issues in the contemporary society. Biodiversity conservation is an urgent matter due to the ever increasing threats. In order to arrest this trend, researches on biodiversity and climate change are necessary on a continuous basis. It is with this background that this paper investigates the impact of climate change on terrestrial animals. The study highlights the problems associated with climate change and biodiversity thereby contributing towards finding solutions on biodiversity conservation amidst effects of climate change. Very few studies have addressed the effects of climate change on terrestrial animals in the selected study areas hence this study addresses and fills the gap in literature in this area. The study also contributes to the professional development component thereby enhancing scholarly work in climate change science.

Methodology

The Study Area

The study area is located in the coastal region of Kenya. Specifically, the study was carried in two counties, namely Kwale and Kilifi in the South and North Coast respectively. Communities in the South Coast are mainly the Digo, while in the North Coast they are mainly the Giriama. Both communities belong to the Mijikenda group of the coastal region of Kenya. The communities are mixed farmers; hence climate and agriculture are key livelihood resources. The ecosystems that formed reference base for terrestrial animals for the study because of the high concentration of such animals are the Arabuko Sokoke Forest in North Coast, (Kilifi County) and Shimba Hills, in South Coast, (Kwale County). The most important ecosystem in the north coast of Kenya is the Arabuko Sokoke forest. The forest is located at 3°16′S39°49′. In terms of area, the park is 6 km^2. Apart from Arabuko Sokoke, other major forest resources in the North Coast include the Dakatcha Woodland and the Dida forest. Arabuko Sokoke is the largest coastal forest (GoK 2016). Part of this forest has been designated as a national park. Shimba Hill National Reserve is located at 04°′26″S39º23′16″E and has an area of 192.51 km^2. Indeed, Arabuko Sokoke and Shimba Hills are conservation areas managed by Kenya Wildlife Service as well as the Kenya Forest Services assisted by other conservation groups.

Research Design

This study adopted a descriptive approach that resulted in data acquisition, analysis and presentation. This design is used as a framework that addresses research questions and gives the methods and procedures used in sampling, data collection and analysis.

Sampling and Sample Size

The study used purposive non-probability sampling method. Ten local community leaders and conservation agents as key informants are used to obtain thematic data on terrestrial animals in the selected areas. Four focus group discussions were organized each with ten local community members to give additional information on climate change and terrestrial animals. Data was analyzed using descriptive statistics and presented graphically in line with the emerging themes.

Results/Discussion

Climate in the Selected Study Areas

It was established that the average annual rainfall in the study area increases slightly from the coast, from 900–1000 mm, to more than 1100 mm. The region receives both long and short rains. The first rainy season ("Long Rains") starts normally towards the end of March. Near the coast the rains are heavy in April and May, and decrease gradually until October in most years without a distinctive end. The second rainy season ("Short Rains") starts indistinctly around the middle of October, and lasts until December or January but with no pronounced end, and variability is high. The unpredictability of the rainfall patterns in the coastal region of Kenya affects human activities and the farming calendar (Othoche 2013).

In terms of temperature conditions, the highest is 34 °C, while the lowest is 22.5 °C. The average temperature conditions are 30 °C though this varies according to seasons and location as well as other environmental factors. The average relative humidity ranges between 60–80%. Wind speed in the region in terms of km/h ranges from minimum values of 4.8 to maximum of 10.9 (Kenya Meteorological Department (KMD) 2014).

Biodiversity in the Study Area

Kenya is rich in biodiversity (World Resources Institute 2007). Generally, the coastal forests have a rich biodiversity. The region has over 50% of Kenya's threatened species of plants, 60% of birds in Kenya and 65% of animals. Large concentrations of terrestrial animals in the study area are mainly found in protected areas such as Arabuko Sokoke and Shimba hills. However, wildlife also lives with communities outside the parks. Indeed, in Kenya, about 70% of wildlife live on private lands (Othoche 2011a, b). Terrestrial animals are also spread across the landscape in private local community land in both the south and north coastal regions of Kenya. This has exposed such animals to human wildlife conflicts.

Terrestrial Animals in North Coast

The most common terrestrial animals in the North Coast include Elephants, Buffalo, Birds, Snakes, tortoise, Crocodiles, Turtles, Fish. The area also has forest reserves, crocodiles and snake parks. Specifically, Arabuko Sokoke protects many endemic and near endemic species of animals to include the birds. The endemic birds include Clarke's Weaver bird. The near-endemic species include Sokoke Pipit, Sokoke Scops Owl and the Amani Sun Bird. Other endemic and near endemic animals include the Golden-Rumped Elephant Shrew, the Sokoke bushy tailed Mongoose, the Ader's Duiker, Savannah elephants, African Civeta, Baboons, Vervet Monkey, and a diversity of amphibians. Arabuko Sokoke has 40 mammals, 270 birds, 49 reptiles, and 25 amphibians (Kenya Forest Service (KFS) 2013a, b).

Terrestrial Animals in South Coast

The most unique ecosystem in the South Coast that harbors most terrestrial animals is Shimba Hills. This is a protected area. Shimba Hills is the center of terrestrial animal concentration in the region. The most common terrestrial animals in the south coastal region of Kenya include the Elephant, the endangered Sable Antelope, Giraffes, Leopards, Hyenas, the Gazelle, the Hippo, Buffalo, Zebra among others. The park also has a number of birds such as the Ostrich, Falcon, Hornbill, Sunbird, among others; reptiles include the Python, Cobra, Lizard, and Gecko) while insects include Butterflies, Mosquitoes, and Beetle). Shimba Hills has 111 birds and 22 of these are coastal endemic. In general, Shimba Hills has about 700 Elephants and 100 Antelopes. Other rare animals include the Hyena and Leopard (Kenya Forest Service (KFS) 2013a, b).

Changing Weather and Climatic Conditions in the North and South Coastal Regions of Kenya

Researches have confirmed that climate and weather patterns in the study area have or are changing (Othoche 2013; Makenzi et al. 2013). A summary of long term average rainfall figures shows variability of the climatic parameters. For the South Coast, (Kwale County) annual rainfall varies between 500 and 1700 mm with a mean of 977 mm of rain. On average the region experiences 60 days of rain per year though this has been fluctuating from as low as 35 to as a high as 100 rain days. Rainfall figures at Shimba Hills shows a decline in average values. The mean annual rainfall value is 1380 mm. The year 2016 average value was only 739 mm. This was the second driest year in the region after 1974 which had 693 mm. Mean rainfall and temperature statistics for North Coast also show fluctuating trends (Table 1).

Table 1 The mean rainfall and temperature statistics for north coast

North coastal region	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2015
Mean annual temperature	29.8	29.6	29.6	30.0	30.3	29.7
Average annual rainfall	875.3	899.8	880.7	957.6	1108.2	910

Source KMD, Mtwapa (2016)

Table 1 shows interdecadal average values of temperature and rainfall conditions for North Coast. It is observed that the mean annual temperatures have remained high with an average figures of 30 °C. The mean rainfall values are also high but with greater monthly and yearly variations. The interdecadal values hide significant variations of very low and very high rainfall patterns. Weather variability is an important indicator of climate change.

In this study, responses from FDs revealed the same trend of temperature and rainfall patterns. The following are some of the manifestations of climate change in the coastal region of Kenya. The responses are given in percentages derived from average values for the four FGDs groups. The responses from ten officials indicate that climate change has threatened terrestrial animals as it affects water resources and pasture. This has resulted in disappearance or migration of animals to better watered parts of the region (Table 2).

There was above average response on the various manifestations of climate change. There was nearly 100% agreement that climate and weather variability in the study area are real. Local communities and officers from selected sites confirmed the situation on the ground. These manifestations have been confirmed in various studies (IPCC 2007, 2013; Othoche 2013). Data from Kenya Meteorological Department (KMD) has revealed that rainfall totals in the study sites and in Kenya in general has been fluctuating from the normal (KMD 2016). This is in line with the findings based on FGDs. Temperatures are on the rise and showing an upward trend in maximum occurrences. This is also in line with the IPCC (2007, 2013).

The Impact of Climate on Terrestrial Animals in the Coastal Region of Kenya

The North and South coastal region of Kenya has a rich plant and animal life. The coastal forests such as Arabuko Sokoke and Shimba Hills are unique ecosystems. These unique protected areas form habitat for terrestrial animals and plants. However,

Table 2 Manifestations of climate change in the North and South Coast of Kenya

S/No.	Climate change manifestations in the North and South Coast of Kenya	Responses (n = 40)	Percentage responses (%)	Remarks
1	Agreement that Climate is Changing in the North and South Coast of Kenya	33	83	North and South Coast
2	Temperatures increasingly becoming hotter and drier	34	85	North and South Coast—Mostly 33 °C instead of the average values of 27 °C for the region
3	Changes in rainfall patterns hence unpredictability	34	85	North and South Coast—Rainfall reliability, seasonality and frequent delays
4	Frequent droughts and heat waves	35	88	North and South Coasts
	Frequent heat waves	35	88	North and South Coast
5	Changes in wind patterns/speed	30	75	North Coast

Source Othoche (2013)

animals that are of less harm to the society roam about freely resulting in human wildlife conflicts (Table 3).

Climate change has also impacted negatively on community livelihoods hence communities target wild terrestrial animals. This further endangers the animals resulting in migration or disappearance. Climate change results in illegal extraction/activities hence increased pressure on wildlife from surrounding communities.

Strategies Put in Place by Stakeholders to Address the Impact of Climate Change on Terrestrial Animals

The key informants gave detailed information on biodiversity conservation and climate change. Due to the adverse impacts of climate change observed in Kenya, a number of strategies have been put in place to address some of the problems. On

Table 3 Impact of Climate Change on Terrestrial Animals (n = 40)

S/No.	Impact of Climate change on terrestrial animals	Strongly agree	Don't agree	Don't know	Remarks
1	Disappearance of birds	29	08	03	*Gongonyika, Kuhe*
2	Drying up of water bodies	37	1	2	*River Bogolo, in North Coast*
3	Reduction in volume of water in some water bodies	38	1	1	*Rivers Athi Sabaki; Chemchem in Kilifi North River Kafuloni*
4	Impact on Terrestrial Animals—Disappearance and/or migration—(*Warthog, Dikdik, wild goat, mud fish, giant snakes*)	37	2	1	*Kilifi North—drying up of river Kafuloni Illegal logging in Arabuko Sokoke Forest due to increase in population and low yields in agriculture as climate change is experienced*
	Migration to Tsavo East National Park—elephant, black rhino	34	4	2	*North and South Coast—drying up of water bodies*
5	Increasing number of pests and vectors—-Mosquitoes, tsetse fly	33	3	4	*North and South Coast—change in temperature conditions*

Source Othoche (2013)

issues related to climate change, Kenya is adopting the United Nations resolution on climate change as outlined in the Kyoto Protocol which was signed by world governments in 1992, finalized in 1997 in Kyoto, Japan and went into force in 2005. The Protocol's mandate is to ensure a reduction in green-house gas emissions and stabilization of the emission concentrations at a level that would prevent dangerous anthropogenic interference with the climate system (Depledge 2000). Kenya therefore participates in the annual COPs which are the offshoot to of the Kyoto Protocol and of which the most current include COP21 in Paris in 2015, COP22 in Marrakech in 2016 and COP23 in Bonn in 2017.

The Kenya Meteorological Department also has encouraged the use of locally available technology to monitor weather and climate variability. There is concerted effort to ecosystem services to be monitored through Ecosystem Based Adaptation, (EBA) which involves use of biodiversity and ecosystem as part of the overall adaptation strategy to the impact of climate change. This includes planting of trees, and cover crops. Due to the various issues observed in relation to climate change, Kenya has put in place policy guidelines for different sectors. Various policies on Climate Change and Biodiversity Conservation have been enacted. There is also collaboration with the international community to address the changing weather and climate patterns. Some of these policy documents include: The National Environment Policy (2012/2013); Forest Policy (2014); The Kenya national Environmental Action Plan (NEAP); the National Development Plan (NDP) Alternative Livelihood Industry; Climate Change Policy (KCP); the National Food and Nutrition Security Policy, 2011, among others. The national and county governments have embarked on campaigns to create awareness among local communities on climate change adaptation and mitigation as well as biodiversity conservation. Indigenous knowledge is being applied at grassroots level in climate change adaptation and mitigation and biodiversity conservation.

There are various strategies that have been put in place to conserve biodiversity in Kenya within the changing climatic conditions. Membership to various biodiversity conservation bodies is a strategy aimed at enforcing the global agenda on biodiversity conservation. The Convention on Biological Diversity (CBD) for example was adopted in the year 2010 during the 10th Conference of Parties (COP10). The objectives of this convention is to develop national strategies for conservation and sustainable utilization of biological diversity (Heinrich 2002). The Cartagena Protocol on Biosafety was adopted in the year 2000 to protect biological diversity from potential risks posed by living organisms resulting from biotechnology. It is a requirement that products from new technologies be based on the precautionary principle. In line with biodiversity conservation bodies, Kenya has also embarked on establishment of protected areas for biodiversity conservation; establishment of zoological gardens which are refuge areas for rare animals that could disappear without captive breeding such as the zoos and aquariums. These are conservation areas for preservation of genetic stocks for re-introduction to the wild when conditions become favorable. They are also used for educational and scientific research.

Botanical gardens/Arboretums are set aside for research and exhibition of plants, documentation of local flora, preserving samples of rare and endangered species and maintenance of specimen collections for future use. It acts as a museum for plants for example, the East African Botanical Garden in Nairobi. Indeed, the National museums of Kenya are actively involved in biodiversity conservation through establishment of botanical gardens. Seed banks have been established as an ex situ approach where storage of conservation materials in form of seeds is monitored with regard to viability through germination tests and purity analysis. National parks and game reserves have been established on terrestrial and aquatic ecosystems with the objective to preserve wildlife that cannot co-exist with human beings and human activities. National parks are under the jurisdiction of central government while game reserves are managed by the local county council (Othoche 2011a, b). Other measures include awareness creation and education of local communities on the importance of protecting the terrestrial animals; ecotourism activities on private land to generate income hence reduce pressure on animals; and enactment of laws on wildlife and biodiversity in general.

Conclusions

Empirical data on climatic variables, from Kenya Meteorological Department and from the officials from Kenya Wildlife Service and Kenya Forest Services, mostly rainfall and temperature have confirmed that there is variability of these climatic parameters. The rains are unpredictable and temperature conditions on the upward trend. There is both temporal and spatial variability of these climatic parameters. Temporal variability is further manifested in daily, monthly, seasonal and annual variability.

This scenario is confirmed by qualitative data from local communities in the study area through FGDs and key informant interviews. Local people observed that climate change and variability has manifested itself in different ways. These include prolonged drought and low and erratic rainfall totals. The Kenya Government through various parastatals has come up with regulatory measures and policies on climate change and biodiversity conservation. There is indeed collaborative effort to involve local communities to accommodate wildlife and be involved in conservation through a shared or participatory approach.

Limitations of the Work

The paper covered selected areas in the north and south coastal region of Kenya. The specific areas included Kwale and Kilifi Counties in the coastal region of Kenya. The paper covered only the impact of climate change and weather variability on terrestrial animals in the selected areas. Rainfall and temperature trends were covered. Primary and secondary were used. However, there are quite a number of ecosystems that offer habitat to terrestrial animals that could be investigate in future studies.

Constraints of the Paper

Timing was a major constraint to this work but this was addressed by use of data collection procedures that ensured acquisition of adequate data for the paper.

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Biodiversity Risks for Belarus Connected with the UV Climate Change

Aliaksandr Krasouski, Siarhei Zenchanka, Elena Loginova and Maxim Andreev

Abstract Ultraviolet radiation (UVR) has a significant impact on human health, state of aquatic and terrestrial ecosystems, biogeochemical cycles and air quality. International agreements on the protection of the ozone layer have contributed to the development of research in this field and in the expansion of the monitoring network for measurement of the ozone layer depletion and the total ozone. The study of various factors that affect ultraviolet radiation is given great attention. A close link and a mutual influence of climate change and changes in the ozone layer have shown during recent studies. Moreover, changes in the ozone layer lead to changes in UVR and influence on biodiversity. The identification of these relationships, the study of the state of the ozone layer and the intensity of UV radiation has become one of the aims of this article. Another aim of the article is to assess the impact of changing UVR levels over the territory of Belarus on the development of elements of wildlife and agricultural productivity. The analysis showed that the main object of exposure for large animals is the organs of vision, whereas for small animals the degree of their coloring is essential. The basic composition of wild vegetation in all landscapes has changed. Typical crops for Belarus were replaced, which led to a change in agricultural technology. This is due to changes in the distribution of climatic zones on the territory of Belarus. Studies have also shown that over the territory of Belarus, unlike the Western Europe, there is still no restoration of the ozone layer, which increases the risks of exposure of the UVR to biodiversity.

A. Krasouski
National Ozone Monitoring Research and Education Center,
Belarusian State University, 4, Nezavisimosti Avenue, 220030 Minsk, Belarus
e-mail: krasovsky@bsu.by

S. Zenchanka (✉)
Minsk Branch of Plekhanov Russian University of Economics,
127 build. 2 Mayakovskogo Str., Minsk 220028, Belarus
e-mail: zench@tut.by

E. Loginova · M. Andreev
Belarusian State University, 4, Nezavisimosti Avenue, 220030 Minsk, Belarus
e-mail: lenaminsk3@mail.ru

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Introduction

Convention on biological diversity (Convention 1992) defines biological diversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems”.

On 25th September 2015 countries adopted new sustainable development goals directed at the transforming our world during the next 15 years (Resolution 2015).

Goal 15 “Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss” refers to the biodiversity conservation. Some targets and corresponding indicators for this goal are presented in Table 1.

These targets and indicators are in close correspondence with the Strategic Plan for Biodiversity 2011–2020 and the Aichi Targets (Strategic Plan 2011) which consider 5 strategic goals and 20 targets. The Strategic Plan provides that “by 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people”.

Table 1 Biodiversity conservation targets and indicators (Report 2017)

Target	Indicator
15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protecting areas, by ecosystem type
15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	15.2.1 Progress towards sustainable forest management
15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	15.3.1 Proportion of land that is degraded over total land area
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	15.5.1 Red list index
15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	15.9.1 Progress towards national targets established in accordance with Aichi Biodiversity Target 2 of the Strategic Plan for Biodiversity 2011–2020

Human activities have led to fundamental changes in our ecosystems and, indeed, they destabilize our ecosystems. The latest assessment on the state of the biosphere (Rockström 2015; Steffen et al. 2015) shows that as a result of human activities, mankind have already crossed four planetary boundaries (climate change, biodiversity loss, deforestation and fertilizer use). It is seen that biodiversity strongly depends on climate change and in its turn the ozone layer depletion contributes to climate change (UNEP 2010, 2014) especially in its regional component (Krasouski and Zenchanka 2018).

In their review Cardinale et al. (2012) presented six consensus statements:

1. There is now unequivocal evidence that biodiversity loss reduces the efficiency by which ecological communities capture biologically essential resources, produce biomass, decompose and recycle biologically essential nutrients.
2. There is mounting evidence that biodiversity increases the stability of ecosystem functions through time.
3. The impact of biodiversity on any single ecosystem process is nonlinear and saturating, such that change accelerates as biodiversity loss increases.
4. Diverse communities are more productive because they contain key species that have a large influence on productivity, and differences in functional traits among organisms increase total resource capture.
5. Loss of diversity across trophic levels has the potential to influence ecosystem functions even more strongly than diversity loss within trophic levels.
6. Functional traits of organisms have large impacts on the magnitude of ecosystem functions, which give rise to a wide range of plausible impacts of extinction on ecosystem function.

There are two aims of the article:

1. The study of the link and a mutual influence of climate change and changes in the ozone layer, which lead to changes in UVR and influence on biodiversity.
2. Assessment of the impact of changing UVR levels on the territory of Belarus on the development of wildlife species and agricultural productivity.

The article consists of the next section:

- Methods:
  - Theoretical approach
  - Instrumental methods.
- Cause-effect relationships: climate change, ozone layer depletion, ultraviolet radiation and biodiversity changes:
  - Ultraviolet radiation and ozone layer.
  - Ozone layer depletion and Climate Change.
  - Impact of UV radiation on biodiversity.

- Results. UV radiation over the territory of Belarus.
  - Investigated areas.
  - Measurement.
- Discussion and Conclusion.

Methods

Two approaches to the investigation were used: theoretical and instrumental.

Limitations of investigation are defined by its aims—the study of the state of the ozone layer and the intensity of UV radiation and the assessment of the impact of changing UVR levels over the territory of Belarus on biodiversity. One more restriction is connected with the limited places of research.

Theoretical approach includes the analysis of scientific reports, programs and articles.

Three sections—Ultraviolet radiation and ozone layer; Ozone layer depletion and Climate Change; Impact of UV radiation on biodiversity—describe different aspects of interaction between climate change, ozone layer depletion and incidence ultraviolet radiation and their influence on biodiversity.

Values of UV power and daily doses of UV for various biological effects (erythema, DNA damage, etc.), as well as the values of the UV Index, were calculated from measured UV spectra in accordance with WMO requirements.

Instrumental methods. The measurements of energy density spectra (EDS) of solar radiation in the spectral range of 285–450 nm on the earth's surface were carried out with the help of ultraviolet spectroradiometer PION-UV and its polar modification PION-F, developed at the National Ozone Monitoring Research and Education Center (http://ozone.bsu.by/).

PION-UV (Fig. 1) is an automatic ultraviolet spectroradiometer.

PION-UV is a compact instrument for measuring absolute intensities and spectral distribution of direct and scattered ultraviolet solar radiation in the spectral range of 280–450 nm intending for use in the monitoring network of solar UV-B radiation, as well as in studies on the effect of UV radiation on natural and anthropogenic ecological systems. The optic of the device is optimized for any measurements of UV radiation; tightness and thermal stability ensure operation in any weather.

Its advantages over analogues are:

- Portability;
- Mobility;
- Low cost;
- Import substitution.

Fig. 1 PION-UV spectroradiometer

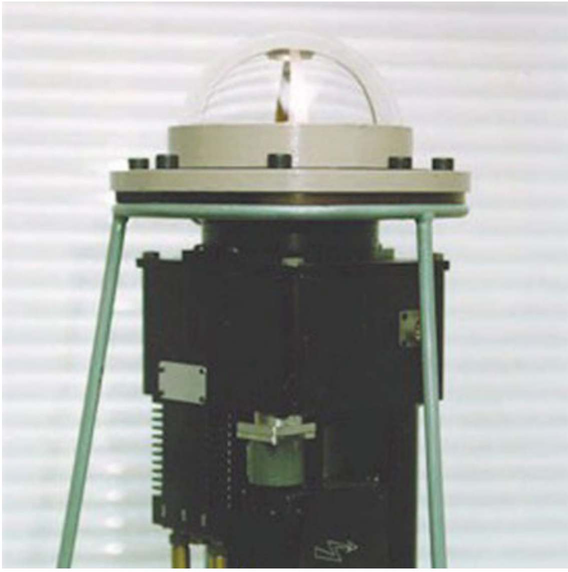

Fig. 2 PION-F photometer

Unlike PION-UV, PION-F (Fig. 2) is an autonomous remote system for monitoring the state of the ozone layer and measuring the dose of active biological ultraviolet radiation (UV Index). It consists of two-channel photometer and a solar panel.

PION-F is completely autonomous and does not require external power sources and communication with a computer for data storage and processing. The results of measurements are transmitted via the GSM network to the remote server, which allows continuous monitoring the ozonosphere online. The autonomy of the system and the use of the GSM network for data transfer allows the photometer to be installed virtually anywhere where there is coverage of the mobile operator, which allows the creation of a network for effective monitoring of the ozonosphere and prompt warning of the risk of UV radiation in the shortest possible time.

Using a modern electronic base allowed to achieve high energy efficiency of the device (the energy consumption in sleep mode is only 13 mW).

The use of microcontroller with ARM architecture allows calculating the total ozone and UV Index directly by the microcontroller program. In addition, the program calculates the time of sunrise and sunset, which automatically allows the photometer to be put into sleep mode at night.

If it is not possible to use the GSM network (for example, carrying out measurements in Antarctica), an alternative wireless communication channel at a frequency of 433 MHz and a maximum range of 1 km is provided in the photometer. In this case, the data are transferred to a PC or laptop.

Cause-Effect Relationships: Climate Change, Ozone Layer Depletion, Ultraviolet Radiation and Biodiversity Changes

Ultraviolet Radiation and Ozone Layer

In recent years, along with the general deterioration of the environmental situation, climate change, pollution of the atmosphere and the aquatic environment, a problem has arisen associating with the effects on the human health of excessive ultraviolet irradiation. The global process of degradation of the Earth's ozone layer, one of the manifestations of which is the formation of "ozone holes", led to the disruption of the usual mode of natural UV radiation.

The sun is the main source of optical radiation coming to the surface of the Earth from space. In quantitative terms, ultraviolet radiation is about 5% of the total flux of solar radiation reaching the Earth's atmosphere. Visible and infrared ranges account for 39 and 56%, respectively (Fig. 3).

The ultraviolet component of solar radiation is called biologically active, as having the most pronounced effect on the living organism. Taking into account the peculiarities of the biological effect, UV radiation is divided into three spectral ranges (Fig. 3): UV-C (radiation wavelength 100–280 nm); UV-B (280–315 nm) and UV-A (315–400 nm).

The most dangerous, with a strong bactericidal effect (leading to the death of microbial cells and viruses), is UV-C radiation. It is completely absorbed in the upper layers of the atmosphere by stratospheric oxygen and the ozone layer and does not reach the surface of the Earth.

UV-B radiation is also absorbed by the ozone layer of the atmosphere and only about 6% reaches the Earth's surface, but it causes the main undesirable effects—burns and skin tumors, diseases of the eyes, depression of the immune system.

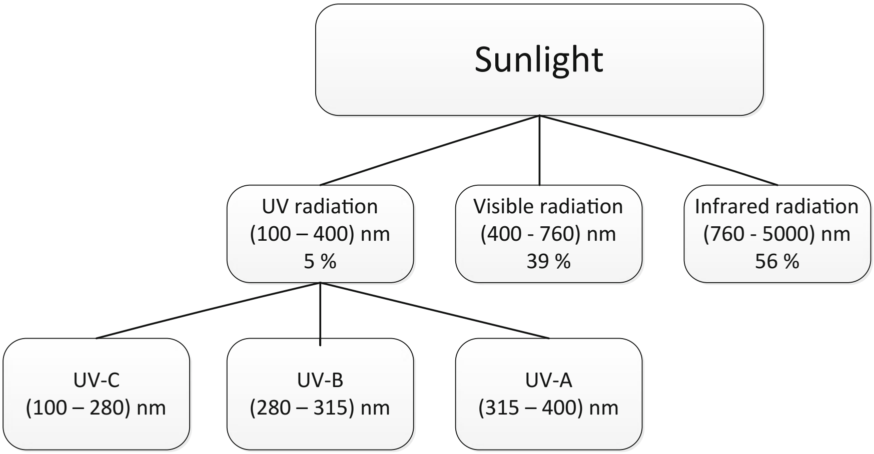

Fig. 3 Solar radiation spectrum

Finally, UV-A radiation is slightly attenuated by the atmosphere, but the biological effect produced by it is approximately 1000 times weaker than that of UV-B radiation.

Given the significant impact of UV radiation on the biosphere and human health, it is extremely important to carry out its constant monitoring, as well as to study the factors which determine the arrival of UV radiation to the Earth's surface.

Ozone Layer Depletion and Climate Change

The strong ozone depletion in the spring months in Antarctica in the early 1980s led to the adoption in 1985 of the Vienna Convention for the Protection of the Ozone Layer (Convention 1985) and the signing in 1987 of the Montreal Protocol on the reduction of the production and consumption of ozone-depleting substances (Protocol 1987). The main goal of the measures taken is to protect the biosphere (primarily to prevent the harmful effects of UV radiation on human health) from the increased doses of UV-C that are possible with the depletion of the stratospheric ozone layer. Given the significant impact of UV radiation on human health and the biosphere as a whole, it is extremely important to conduct its constant monitoring, as well as to study the factors determining the arrival of UV radiation to the Earth's surface

In addition to influencing the intensity and spectral composition of UV radiation, changes in the ozone layer lead to climate change (Hegglin et al 2015; UNEP 2010, 2014).

Krasouski and Zenchanka (2017) consider two mechanisms of interaction "ozone layer depletion—climate change": "the "radiation" mechanism which is responsible for the formation of ozone in the upper stratosphere and lowers the height of the tropopause, the other operates in the troposphere and called "thermodynamic". It creates conditions for the dry and moist instability and thereby raises the height of the tropopause and decreases the total ozone content. Mutual influence and the relative role of tropospheric ("thermodynamic") and stratospheric ("radiation") mechanisms vary according to region and season. Thermodynamic processes (convection) prevail in the tropical region. “Radiation” mechanism prevails in the unstable troposphere and in the polar latitudes”.

Changing of regional climate distributes biodiversity at local sites.

Impact of UV Radiation on Biodiversity

The Sun UV radiation always plays important roles in our environment, and affects nearly all flora and fauna. The changing of UV irradiance can affect primary production in all ecosystems, terrestrial and aquatic, natural, managed, or exploited with a potential cascade of effects. Current understanding of these processes does not enable confident prediction of the impacts. Chapin, Sala and Huber-Sannwald (Scenario 2013) pointed that “little is known about the effects of increasing UV-B on either biodiversity or ecosystem function”. It is necessary to consider as positive as negative impact of UV radiation on living organisms and plants.

There are serious impacts of ozone depletion on biodiversity. For example, increased UV radiation reduces the levels of plankton in the oceans and subsequently diminishes fish stocks. It can also have adverse effects on plant growth, thus reducing agricultural productivity. A direct negative economic impact is the reduced lifespan of certain materials.

In forests and grasslands increased UV-B radiation is likely to result in changes in species composition (mutation) thus altering the bio-diversity in different ecosystems. Physiological and developmental processes of plants are affected by UV-B radiation, even by the amount of UV-B in present-day sunlight. Despite mechanisms to reduce or repair these effects and a limited ability to adapt to increased levels of UV-B, plant growth can be directly affected by UV-B radiation (Secretariat of the Convention on Biological Diversity 2014).

The negative impact on living organism is connected with eye diseases, the defeat of the skin, malfunctions in the immune system, On the other hand, the positive effect of UV radiation on living organisms is connected with synthesizes the vitamins of group D necessary for health, which prevent the development of such diseases as rickets, osteoporosis and some types of cancer.

Plants, as primary producers, are fully dependent on solar radiation. Light is the source of energy for them, driving photosynthesis and directing development from germination to flowering. UV radiation might increase the amount of active substances in medicinal plant. However, sunlight, especially its UV component, can cause negative effects on plants: decreasing the plant growth, changing plant color, plant productivity, etc.

These three sections—Ultraviolet radiation and ozone layer; Ozone layer depletion and Climate Change; and Impact of UV radiation on biodiversity—show mutual interaction of climate change and ozone layer depletion, and their influence on the intensity of the UV radiation which impact on elements of biodiversity.

The Results. UV Radiation over the Territory of Belarus

Investigated Areas

Monitoring of power, doses of biologically active solar radiation and UV Indexes are carried out at the Minsk Ozonometric Station of the NOMREC, bio-station of the Belarusian State University on Lake Naroch, as well as at the meteorological site of the Gomel University (http://ozone.bsu.by/instruments.htm). These three places are disposed at different parts of the Belarus belonging to different climatic zones (Loginov 2017). Besides that Lake Naroch is a recreation area and measurement of UV Indexes is very important for peoples' health.

Measurement

Monitoring UV radiation is becoming more and more important, especially in view of the continuing changes of the processes in the ozone layers of the atmosphere and the consequent effects on the environment and physical health. As mentioned by Chubarova et al. (2016) the pattern of temporal and spatial variability of the UVR is rather complicated due to the impact on it of variations not only of ozone, but also of other geophysical factors—cloudiness, aerosol, and surface albedo. It should be noted that in many regions in recent years a noticeable increase in UV radiation.

At Figs. 4 and 5 the results of UV Index measurement are shown.

In accordance with the recommendation of the WHO and WMO the UV Index uses to assess the degree of risk of UV radiation exposure for human (WHO 2002). The

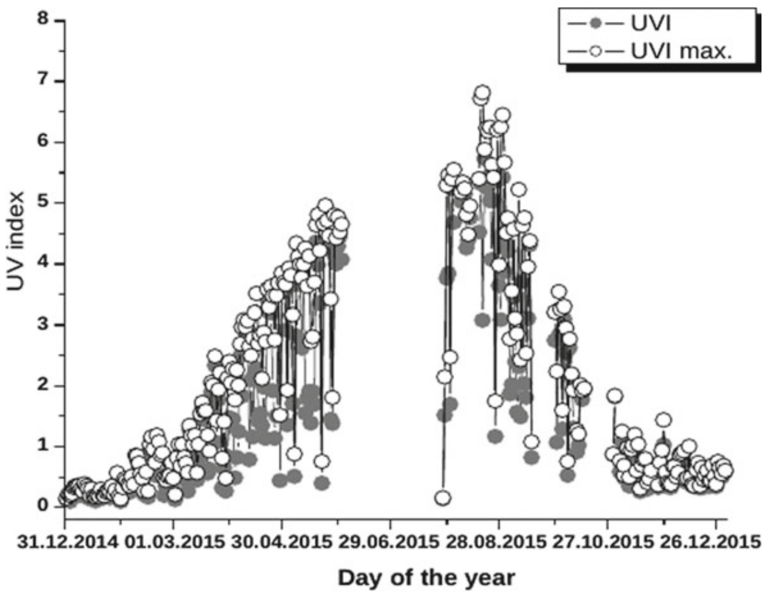

Fig. 4 The UV Index in Minsk

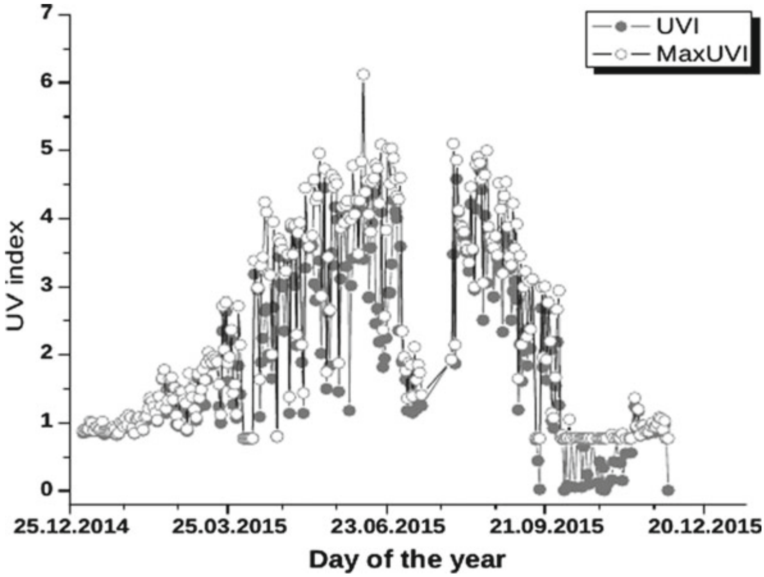

Fig. 5 The UV index near Lake Naroch

UV Index (UVI) is calculated from measurements of total ozone (TO) and maximum levels of UV radiation (UV maximum) making in an astronomical afternoon. UVI maximum defines risk of maximum irradiation of human, ecosystems, etc. in the absence of clouds. The real UV Index was measured and then it was re-calculated using the average value of UVR level in the period from one hour to and one hour after astronomical afternoon. This level is always less than the maximum. The daily behavior of UV Index can be modeled by changing the zenith angle. Information on the UV Index is used to determine the potential danger of excessive exposure of sunlight on human health. As can be seen, the maximum of the UV Index (maxUVI) is observed in the spring-summer and summer-autumn periods.

Data on the spectral composition and intensity of UV radiation are used to calculate the doses of biological effects of erythema, DNA damage, cataracts and skin cancer.

"Erythema dose" is an amount of radiation that, when applied to the skin, causes erythema (temporary reddening).

Figure 6 presents the results of retroanalysis of the total annual "erythema dose" for the Lake Naroch area.

This curve was obtained by re-analysis using data on the recovery of ozone, mean cloudiness and aerosol content. Maximum "erythema dose" in 1995 coincides with the existence of an ozone hole over the territory of Belarus.

The average annual dose of biological effects of erythema, skin cancer and cataracts in the Minsk region is 400, 800 and 1500 kJ/m^2, respectively. The main con-

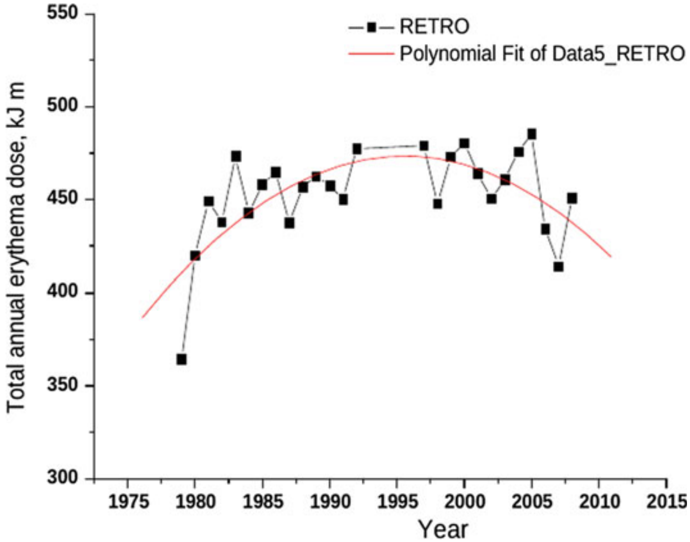

Fig. 6 The total annual "erythema" dose for the Lake Naroch area

tribution to the total annual dose of UVR is given by six months of the spring-autumn period, they account for about 85% of the annual dose.

Despite the successes achieved in the conservation and sustainable use of biological diversity, the impact of negative factors on natural ecological systems and populations of species of wild animals and wild plants of the Republic of Belarus continues.

One of the main factors of natural origin is climate change, which leads to aggravation of competition between aboriginal and alien species of wild animals and wild plants, the formation of conditions favorable for the development of diseases and pests. Under the influence of global climate changes, the area of boreal species of wild plants and wild animals has been reduced, a number of new species typical of the steppe and forest-steppe zones have been observed, a decrease in the number of populations of certain species of wild plants and wild animals in a floodplain, coastal and wetland ecological systems.

The analysis of the yield of agricultural crops was carried out between 1990 and 2015 on the basis of the data of the statistical committee (http://www.belstat.gov.by/ofitsialnaya-statistika/realny-sector-ekonomiki/selskoe-hozyaistvo/). This analysis showed that the yield of the main crops (barley, rye, wheat) tends to increase and coincides with the trend of climate change and with the shift of climatic zones. Similar data for the period 1979–2011 are presented by Hitrikau (2015).

Discussion and Conclusion

Several problems were considered in the article: UV radiation and its link with ozone layer depletion; ozone layer depletion and climate change; measurement of UV radiation; and impact of UV radiation on elements of wildlife and agriculture.

Importance of constant monitoring of UV radiation and the factors which determine the arrival of UV radiation to the Earth's surface was considered taking into account significant impact of UV radiation on the biosphere and human health.

The role of "radiation" and "thermodynamic" mechanisms responsible for the formation of ozone in the upper stratosphere and lowers the height of the tropopause was discussed.

The methodical part of the work considers the theoretical and instrumental approaches to the study of the ozone layer, the intensity and distribution of UV radiation. Brief descriptions of two UV measurement devices are given.

The obtained results show the seasonal dependence of the UV Index and its dependence on geographic coordinates. In the mid-latitudes, the UV Index values are in the range 1–10 and depend mainly on the height of the Sun above the horizon, the total ozone content in the atmosphere, the cloudiness and the state of the underlying surface. Values of UV Index for risk assessment are presented in Table 2.

UV Index for Minsk region can reach 7 in autumn what corresponds high level of risk, but of Lake Naroch region, it reaches only 5 what corresponds middle level of risk.

The calculated "erythema curve" at the maximum coincides with the period of the ozone hole over the territory of Belarus.

The effect of the ozone layer and the associated intensity of UV radiation on wildlife and plants, as well as on crops, is considered. On the basis of statistical data, an increase in the yield of agricultural crops is shown. This is concerned with regional climate change in which "radiation" and "thermodynamic" mechanisms of "climate change—ozone layer depletion" interaction make a contribution. Changes in climatic zones have led to the appearance of unusual for Belarus species of birds (Phylloscopus inornatus, Pelecanus Crispus, Larus michahellis, Larus hyperboreus) (http://greenbelarus.info/articles/26-12-2016/4-novyh-vida-ptic-zaregistrirovali-v-belarusi). Besides that, some species of plants may disappear from the territory of Belarus because of climate warming, especially for boreal species such as spruce, mistletoe, etc.

Table 2 UV Index and degree of irradiance (human risk)

Risk	UV Index
Low	≤ 2
Middle	From 3 to 5
High	From 6 to 7
Very high	From 8 to 10
Extremal	≥ 11

National Ozone Monitoring Research and Education Center plans to increase ozone and UV monitoring network in Belarus by placing measuring devices in all regional centers. In addition, during the past few years, NOMREK has been involved in ozone layer research in Antarctica as part of the Belarusian Antarctic Expedition and will continue these studies in the future.

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Aliaksandr Krasouski is Associate Professor of Geography Departament of Belarusian State University, and has a Ph.D. in Physics. He is a founder of National Ozone Monitoring Research and Education Center of the Belarusian State University. His research focus is in the area of ozone monitoring, meteorology and “ozone depletion-climate change” interaction.

Zenchanka Siarhei is a professor of the chair of Management, Accounting and Finance of the Minsk Branch of the Plekhanov Russian University of Economics. He has a Ph.D. in Applied Science. His research focus is in the areas of the sustainable development and education for sustainable development.

Elena Loginova is Associate Professor of the Geography Departament of Belarusian State University, and has a Ph.D. in geography. His research focus is in the areas of the climate change and biodiversity.

Maxim Andreev is a 5-years student of the Geography Departament of Belarusian State University. The results, presented in article, will be included in his graduate work.

The Impact of Forest Fire on the Biodiversity and the Soil Characteristics of Tropical Peatland

Cahyono Agus, Fatikhul F. Azmi, Widiyatno, Zinda R. Ilfana, Dewi Wulandari, Dony Rachmanadi, Marinus K. Harun and Tri W. Yuwati

Abstract Land use change and forest fire covering millions ha of peat-land in Central Kalimantan are the main factor contribute on forest peatland degradation. This study aimed to determine the impact of forest peatland fire severity level on the plant diversity and soil chemical properties of wet tropical peatland in Central Kalimantan, Indonesia. The severe peat fire extremely decreased diversity, number of individuals as well as number of plant species. The accumulation of ashes in forest peat fires impacted area instantly increased pH, organic matter, humic acid content, hydrophobicity, available-N and available-K. However, their availabilities had only been temporary as they were easily diminished and washed way which result in long-term land degradation. An opened and dried peatland had low water holding capability and, hence, it was relatively easy to burn during the dry season but flooded during the rainy season. Tropical forest peats fires significantly reduced plant diversity and changed soil chemical properties. This forest peat fire potentially loss its function, particularly moisture storage, carbon, nutrients and biodiversity.

C. Agus (✉) · F. F. Azmi · Widiyatno · Z. R. Ilfana
Faculty of Forestry UGM Bulaksumur, Yogyakarta 55281, Indonesia
e-mail: cahyonoagus@gadjahmada.edu

D. Wulandari
SEAMEO BIOTROP, Bogor, Indonesia

D. Wulandari
Universitas Islam Indonesia, Yogyakarta, Indonesia

D. Rachmanadi · M. K. Harun · T. W. Yuwati
Banjarbaru Forestry & Environment Research & Development Institute, Banjarbaru, Indonesia

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Introduction

Indonesia is the country with the widest tropical peatland area in Southeast Asia, which covers 20,695,000 ha or 81.7% of the total tropical peatland in Southeast Asia (Rieley et al. 1996b). Peat swamp forest is one of the wet land type which its existence has been most threatened by human activities. Land use change of forest' function into agriculture or plantation may threaten the existence of the natural peat swamp forest. It is reported that the carbon content of peatland in Sumatera was 22,293 million tons in 1990 and it was decreased into 18,813 million tons in 2002 (Wahyunto et al. 2004). It means that in 12 years periods (1990–2002) the carbon reserve decreased approximately 3470 million tons or 289.16 million tons per year of the total carbon reserve in peatland in Sumatera. Land use change and over exploitation of tropical forest ecosystem lead to the land degradation and damages (Agus et al. 2004, 2011, 2016, 2017; Agus 2013, 2018; Kita et al. 2008; Cahyanti and Agus 2017; Asdak 2002).

Degradation of peat swamp forest ecosystem may result on the loss function of hydrology, biogeochemical, biodiversity and ecology. This is because peat swamp forest represents flood buffering space, water reservoir during dry season, filtering system of water quality, and habitat of various germplasm. The peat swamp area plays an important role as producer of woods, food stuffs, and living and breeding environment of water biota, soil microbiota as well as various life supporting systems. Furthermore, swamp area also supports the historical role, cultural values, science, and other social systems (Barchia 2006).

Forest fire presents significant impact on the condition of peatland, particularly on its function as carbon reserve. Forest fire will likely emit a huge quantity of carbon dioxide. According to Krisnawati et al. (2015), the carbon dioxide emission in Central Kalimantan resulted from the forest fire was 24,305,601 tons, 348,780 tons, and 10,565,491 tons in 2009, 2010, and 2011 respectively. As one of greenhouse gases, the carbon dioxide triggers global warming. Forest fire affects peatland by producing CO_2, CO and hydrocarbon. The CO resulted from incomplete burning of forest fire may emit greenhouse gases as one of global warming contributor. In addition to the CO, forest fire may also result on high particle emission that poses danger for human's health. The quantity of the particle resulting from the forest fire will accumulate in atmospheric moisture which then form thick fog (Adinugroho et al. 2005). Indonesia has committed to reduce the emission of the greenhouse gases up to 26% under business as usual (BAU) level in 2020 and to up to 41% if there was an international support (Krisnawati et al. 2015).

Indonesia's wet tropical forest provides rich biodiversity. However, forest fire, illegal logging, and irresponsible human activities greatly contribute in the reduction of the width of the forest area over the years. Forest fire causes degradation and inflicts on economical, ecological, social and cultural losses. Moreover, it has caused the failure in the implementation of sustainable forest management. In another word, it has been unable to fulfill the existing ecolabel requirements. Economically, it causes loss of forest resources, decrease the potential result of lumbers representing one of the basic capitals in national development. Furthermore, it may also decrease both the quantity and quality of biological natural resources along with the ecosystem which serves the function of supporting life. This, in effect, would decrease t diversity of flora and fauna as the sources of germplasm, quality of soil, change in forest hydrological function as well as global warming. The forest fire that had affected peatland has significant impact on the global warming as the peatland played an important role in carbon, water and geothermal cycles. It was therefore necessary to conduct a study of the soil characteristics and the vegetation composition of the area affected by the forest fire.

The Distribution of Peat Swamp Forest

There is 37,734,300 ha tropical peatland in the world (about 10–12% of global peatland), distributed in South America, Central Asia, Southeast Asia, Africa and pacific countries. About 67.1% of the tropical peatland worldwide can be found in Southeast Asia, which is 25,329,400 ha (Rieley et al. 1996b). Indonesia has the widest tropical peatland in Southeast Asia, which covers 20,695,000 ha or about 81.7% of the total tropical peatland in Southeast Asia (Rieley et al. 1996b), distributed in Kalimantan (6.79 millions ha), Sumatra (8.25 millions ha), Irian Jaya (4.62 millions ha) and the remaining peatlands distributed in Sulawesi, Halmahera and Seram (Radjagukguk 1997).

According to Wahyunto et al. (2004), peatland in Kalimantan has the maturation levels of 'Fibric' (i.e., in raw condition and has not undergone weathering process), 'Hemic' (i.e., half-weathered), 'Sapric' (i.e., completely weathered/dissolved) and/or the combination of one of the three or the entire three levels. The thickness of the peatland in Kalimantan varies from very thin (<50 cm) to very thick (>8 m). It has been estimated that the carbon content of the peatland in Kalimantan was 11.3 giga tons (GT).

The Diversity of Plant Species in Peat Swamp Forest

Peatland represents an important land resource for people as it produced lumbers (including ramin, meranti, belangiran, bamboo, nyatoh, kempas, pulai, terantang, geronggang, mahang, punak, betanggur and balam), clothing materials (including leaves and barks), food stuffs (including paddy, corn, sago, tubers and vegetables), and even herbal medicines (including kepayang, krinyu, katalayu, lukut, galam, luwa, rengas, sarigading, jingah, gulinggang), as well as fitness materials (including pasak bumi and gingers) and industrial materials (including rattan, hemp and jelutung). There are also many annual plants growing in the peatland such as coconut trees, coffee trees, rubber trees, oil palms, pepper, orange, rambutan, durian, cempedak, jackfruit and pineapple. There are also rare and exotic fruits found in the peatland such as big mangosteen (*Garcinia* sp.), sweetsop fruit (*Anona* sp.), red flesh durian (*Durio* sp.) and its family members like pampakin, lai-lidung, lahong, mahrawin, kamundai, and likol/leko (*Durio graveolens*). Family members of rambutan such as taap and kopuan (*Arthocarpus* spp.), butter fruit (*Diospirus discarlon*), pitanak (*Leukocinitis* spp.), gitaan (*Leukconitis corpidae*), rambai padi (*Baccaurea mutleana*), kapul/puak, ramunia (*Bouea macrophylla*), and balasungkawa (Noor et al. 2007) also has its contribution. There are about 60 species of trees with economic value which produces lumbers (Barchia 2006) in addition to about 310–376 species of other plants in the peatlands in Kalimantan and Sumatera with the density of 1300–3200 individuals per hectare (Wibisono 2005). There are also many species of fishes, birds and other fauna found in the peatland that are rich in protein, fat, vitamin and mineral sources. There are about 104 wild faunas, including 32 mamalia (13 protected species), 8 reptiles (5 protected species), 60 species of birds (9 protected species). It has been predicted that there are about 100–500 species of fishes found in the peat swamp waters (Dahuri 1997).

The Characteristics of Peat Soil

Tropical peatland is composed of litters of various plants growing in the tropical swamp forest, consisting of stems, branches, raw roots that were still indicative of their original plants. Driessen (1978) describes that physical characteristics of peatland soil is a result from a number of variables which influence each other. One of the physical characteristics of the peatland soil which often to be compared to mineral soil is soil moisture content. The capability of the peatland soil to keep moisture is greatly significant, ranging from 200 to 1000% based on weight or 50–90% based on volume (Andriesse 1988). The capability of the peatland soil to keep water is significantly influenced by the maturity of peat and groundwater depth (Rieley et al. 1996a). Fibric peat material able to keep the moisture of 500 and 1000% of weight, while hemic and sapric peat materials only able to keep the moisture of 200 to 500% of weight. In saturated water condition of catotelm zone, the fibric peat material may keep much more moisture than hemic and sapric peat materials. However, in non-water-saturated condition or in acrotelm zone, the capability of the peat material varies with its distance to groundwater surface. Bulk density represents the most important characteristics because some other characteristics of the peat soil are closely related to it (Andriesse 1988). Compared to the mineral soil, the bulk density of the peat soil is much lower. The bulk density of tropical peat soil is generally lower than that of non-tropical soil, ranging from 0.1 to 0.3 kg dm^{-3} and it usually decreases with depth (Rieley et al. 1996a).

The tropical peatland is characterized by low nutrient content and high acidity (Rieley et al. 1996a) as a result from the formation process of its peat materials which is influenced by rain water deficient of minerals. The composition of the nutrients is highly dependent on the plant‘s nutrient composition produced by litters.. The majority of the tropical peatland contains less than 5% minerals. The total content of chemical elements of ombrogen peatland is lower than that of topogen peatland and mineral land (Rieley et al. 1996a). The macro and micro elements contained in the low layer of the peatland are usually lower than that of the upper layers (Ahmad-Shah et al. 1992). Thus, nutrient deficiency often has its occurrence in thick and ombrogen peat land.

The total nitrogen (N) content of the tropical peatland in some areas in Indonesia ranges from 0.3 to 2.1%, in Malaysia 0.9–1.7%, and in Brunei 0.3–2.2% (Sajarwan 1998). The range of available mineral-N for plants is less than 1% from total N content. The mineral nitrogen contained in the peatland is not easily available for the plants because of its high C/N ratio, which is range from 25 to 50 (Jali 1999). The majority of phosphor (P) in peatland is in the form of organic-P and only small amount of the organic-P is in the form of organic-P compound. The available soil-P is more likely depend on the mineralization results of the organic-P compound. The mineralization and the immobilization of the P by microorganisms is significantly influenced by the C/P ratio of the peatland (Tisdale et al. 1985). The total P content of the tropical peatland is generally less than 0.1% and its C/P ratio is 15–20 times lower than the C/N ratio (Jali 1999).

The Tropical Peatland Fire

The forest fire that has affected the tropical peatland, especially in Southeast Asia, has taken place in a long period of time. Usually, it occurs during dry season, especially in reclaimed peatland areas. The first severe forest fire occurred in 1982/1983 during the El-Nino dry season in which about 500,000 ha of the peatland, especially in East Kalimantan was burned out (Page et al. 2002). Another severe forest fire took place in 1997/1998 and affected about 1.5 million ha of the peatland in Indonesia (BAPPENAS 1998). Among the affected areas, 750,000 ha are located in Kalimantan, which included approximately 500,000 ha at PPLG in Central Kalimantan (Page et al. 2002).

The forest fire during the dry season might be triggered by natural occurrences such as dried branches and leaves which are unintentionally burned by human. Some major causal factors of the fire related to human are burning practice to clear the land for agricultural purposes, land drainage, logging, human recreation activities such as camping and excursion, hunting and fishing, especially electrical fishing (Abdullah et al. 2002). The forest fire in Malaysia is caused by land clearing for agricultural use (Abdullah et al. 2002). Meanwhile, forest fire in Central Kalimantan is assumed to be related to forest clearing and drainage of peatland. This is because 80% of the fire spots are found in the PPLG area and concentrated around the drainage and irrigation canals (Page et al. 2002).

The forest fires may give either direct and indirect impact to peatland. The direct impacts of the fire are, among others, the loss of the upper layers of litters of the peatland (Jaya et al. 2000), the decline in the biodiversity, the environmental degradation, and the deteriorating of health condition of living organism in the surrounding areas affected by the fire (Musa and Parlan 2002). The forest fire in Central Kalimantan in 1997/1998 causes the decrease in the vegetation density, loss of 75% of the peatland of 35–70 cm of depth, and loss of 0.2–0.6 Gt carbon (D'Arcy and Page 2002). Furthermore, Noor (2010) reported that a million hectare of opened peatland in Central Kalimantan has annually contributed 0.425 million tons of CH_4 to the global emission of greenhouse gases. The carbon emission of the peatland opened for agricultural use approximately 2.25–3.74 tons C/ha/year. Thus the opening of a million hectare of the peatland would have the potential emission of the greenhouse gases equivalent to 8.07–13.58 million tons CO_2 annually. The lost carbon has extraordinarily significant impact on the emission of CO_2 into atmosphere. Meanwhile, the indirect impacts of the forest fire that affect the peatland represents the post-effects resulting from the recovery process of the peatland both naturally and deliberately by human being into its original condition. This may have happened for many years depending on the capability to recover the peatland and also the quality of the peatland itself. There has not been any study reporting the post-effects of the forest fire that have affected the peatland's characteristics. After the forest fire, the canopy of the forest was more opend and the peatland became more exposed. Consequently, the peat soil was more opened to atmosphere (aerob) compared to its natural condition. Therefore, it was predicted that the characteristics of the peatland would change after the fire.

Ffolliot and Bennet in De Bano et al. (1998) classified the severity of the forest fire based on the observed damage of trees into:

- *Low fire severity*: at least 50% of trees are indicative of observed damage caused by the fire such as the burned crown, the dead shoots (the upper parts were burned, but germinating) or the dead roots, while >80% of the damaged/burned trees survive.
- *Moderate fire severity*: 20–50% of trees are indicative of unobserved damage caused by the fire, 40–80% of the damaged/burned trees survive.
- *High fire severity*: <20% of trees are indicative of unobserved damage, the majority of the damages resulting from the fire is observed in the dead roots, while <40% of the damaged/burned trees survive.

The Degraded Land After Forest Fire in Kalimantan

The impact of the above 3 kinds of forest fire severity on the characteristic of biodiversity and soil were studied in the Special Purpose Forest (KHDTK) of Tumbang Nusa located in Jabiren Raya Sub-district, Pulang Pisau District, Central Kalimantan which was under the management of Indonesian Center for Environment and Forestry Research and Development (BP2LHK) Banjarbaru. The forest fire in 2015, was one of the biggest forest fires that has ever taken place in the area of KHDTK Tumbang Nusa showed that more than 50% of the area of the KHDK Tumbang Nusa was burned at various severity levels.

Secondary forest represented the land with the biggest number of individuals that was not affected by the forest fire in 2015. There were 106 individuals found intact,

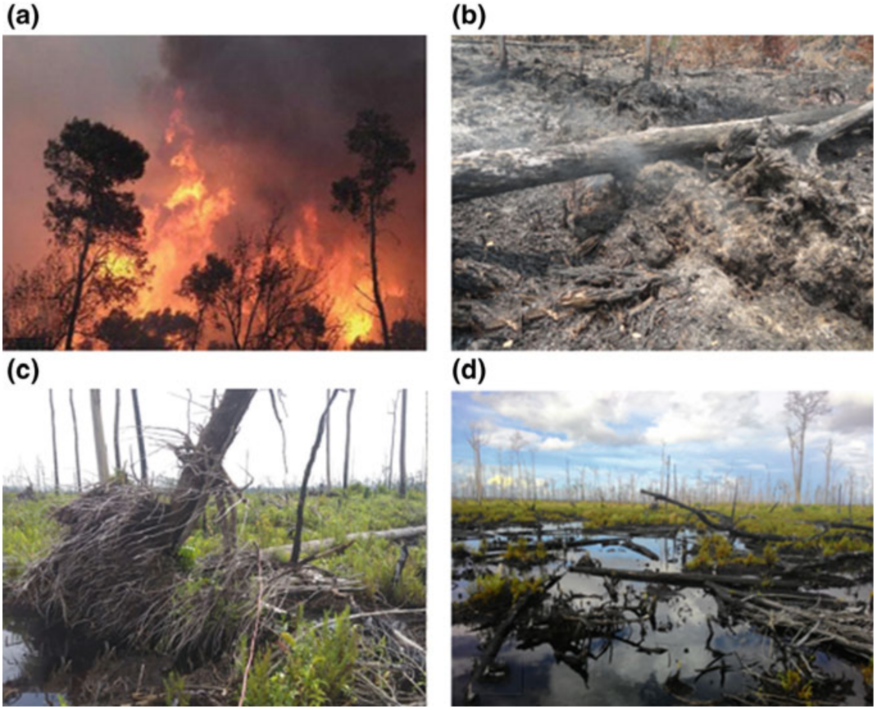

Fig. 1 The condition of the forest during the fire and after the fire in 2015. **a** The condition of ground fire that caused burned crown. **b** The condition of the ground soon after the severe fire. **c** The dead roots followed by falling down of the trees because of the fire. **d** The condition of the severe fire a year after the fire. *Source* BP2LHK Banjarbaru

consisting of 8 species of trees. Furthermore, there were 44 individuals of trees survived, consisting of a species. Meanwhile, there were 16 trees found dead in the land which means 73.33% of the trees survived of the forest fire in 2015. The severely burned land without any vegetation cover had only 4 remaining trees after the fire in 2015. Meanwhile, the condition of the severely burned land with vegetation cover was the same as that of the burned land without any vegetation cover after the fire in 2015 in which all of the trees had been burned out and there were only a very small number of surviving trees. However, after the fire, the land with vegetation cover experienced natural rejuvenation that the in-field data of the vegetation gathered in 2017 were indicative of the increase in the number of individuals and the species.

The most severe fire was ground fire which the heat under surface of the ground caused the death of trees resulted from burned-out roots. In effects, trees were unable to survive. Moreover, the ground fire also led to surface fire that reached the crown (Fig. 1a). Almost all of the trees in the area had burned out leaving only the standing burned trees (Fig. 2d). The severe damage resulting from the severe fire is presented in Fig. 1.

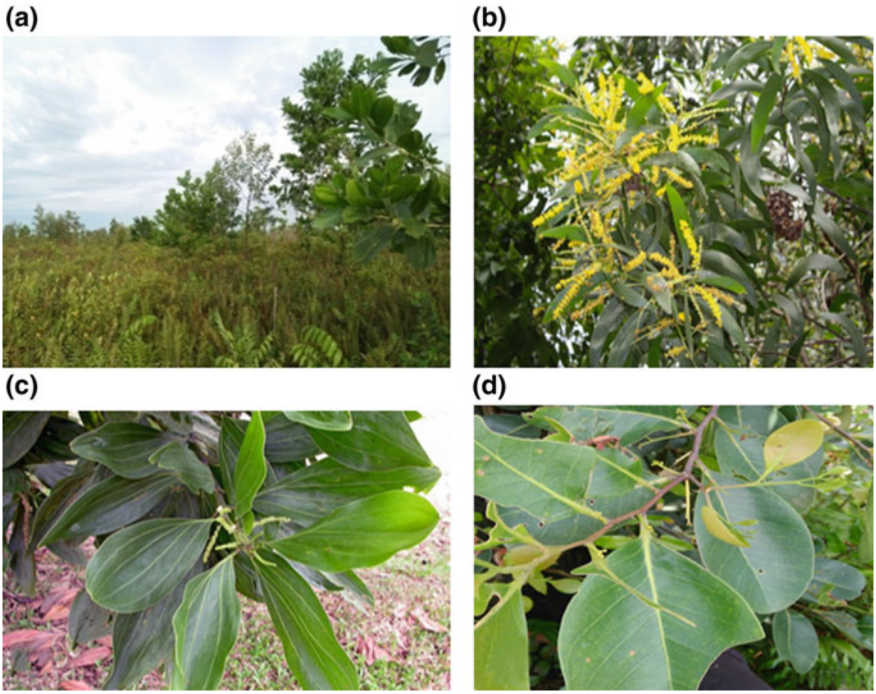

Fig. 2 The condition of the land after severe fire that has been covered by vegetation. **a** The general condition of the land. **b** The growing species *Acacia auriculiformis*, **c** The growing species *Acacia mangium*. **d** The growing species merapat/tumih (*Combretocarpus rotundatus*)

The condition of the land after the severe fire showed that the land has been covered by vegetation and this occurred in the land having bigger number of stands and higher trees compared to the land that has not been covered by vegetation after the fire. Figure 2 showed the condition of the land after the severe fire. It has been covered by the vegetation of the species of *Acacia mangium*, *Acacia auriculiformis*, and merapat/tumih (*Combretocarpus rotundatus*). The increase in the number of the vegetation two years after the fire in the severely burned land had been covered by the vegetation. It might be due to the presence of sidewalk plants that helped distribute the seeds of the acacia with the blowing wind. Thus species became invasive as the land was situated 20 m from the main road in which the *Acacia mangium* represented the species growing on the sidewalk. This is the pioneering species able to naturally regenerate itself in severely damaged location. It has able to adapt to various types of soil and environmental conditions.

The land that had been severely burned without any vegetation represented small number of stands and trees. The existing remaining individuals were the survivors of the severe fire. The absence of acacia in severely burned land might be due to the long distance of this area from main road which approximately 1 km. This long distance might hamper the seed distribution. Therefore, there was a significant difference

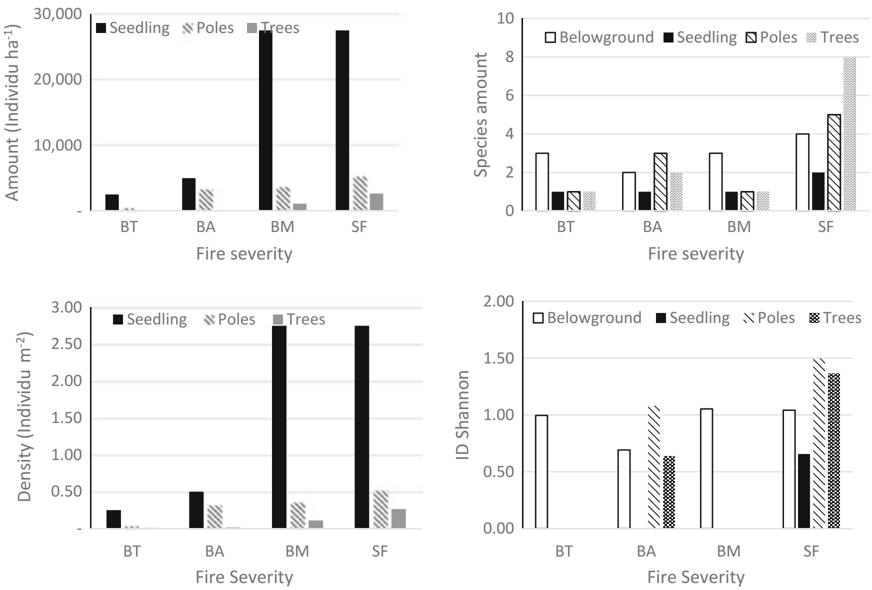

Fig. 3 The number of the individuals and the species, the density of the vegetation and Shannon's Diversity Index at various growth levels and fire severity. *Note* BT—severely burned without any vegetation cover, BA—severely burned with vegetation cover, BM—moderately burned, SF—secondary forest

between the two areas of the affected land in terms of their vegetation condition after the fire

Vegetation measurement on trees and their rejuvenation showed that secondary forest had 4 species for ground plants, 2 species for seedling level, 5 species for stake level, 8 species for pole, and tree level (Fig. 3). Figure 2a illustrates the condition of the secondary forest in which the species of Balangeran (*Shorea balangeran*), Gerunggang (*Cratoxylon arborescens*), Meranti (*Shorea* spp.), Merapat (*Combretocarpus rotundatus*), Meranti Daun Lebar (*Shorea uliginsoa*), and other species were found. The number of the individuals and the species tended to increase because of the minimal presence of interference.

The number of the species at growth levels of seedling, stake, pole and trees after the moderate fire was very low, a species for each was Merapat *Combretocarpus rotundatus*). Merapat is the local species of Kalimantan well-known as fire resistant because of its thick bark. It was evidenced in 73.33% of the trees remained after the moderate fire. The causal factor of the big number of the surviving trees after the fire was the presence of the fire resistant species in higher severity level of the fire. Land with moderate fire level only affected on the surface of the ground, did not affect the lower layers, and did not burn crown unlike in the land with severe fire.

The number of the individuals at all growth levels tended to decrease with the severity of the fire. However, the value was more likely to vary at the growth level

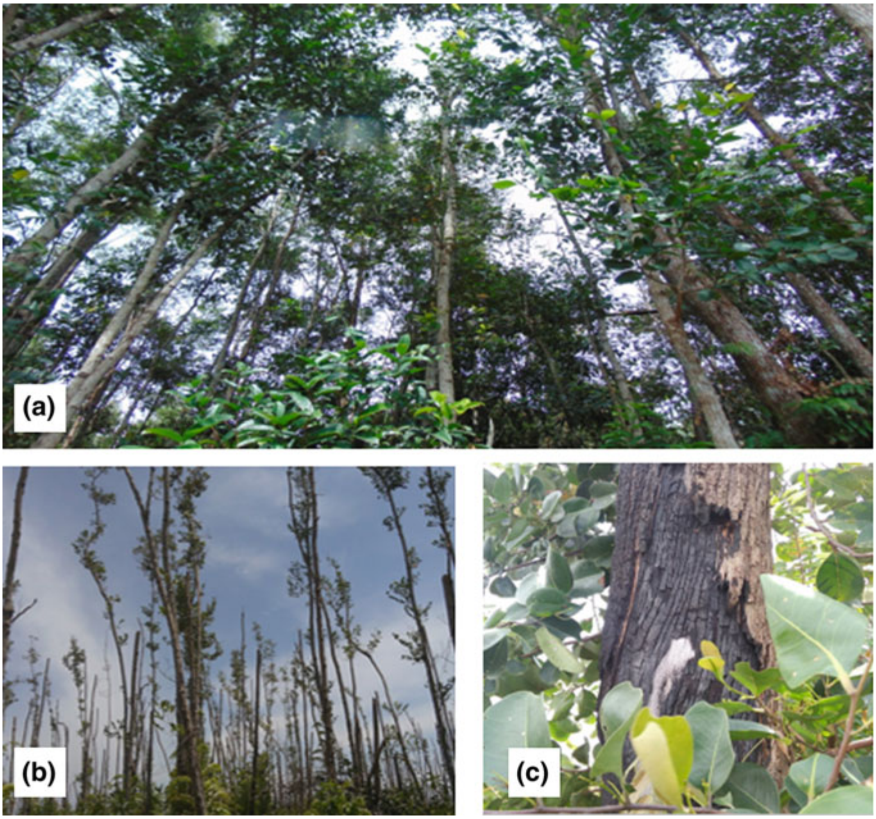

Fig. 4 **a** The condition of the vegetation covered in secondary forest. **b** The condition of the land after the moderate fire that was dominated by the species Merapat (*Combretocarpus rotundatus*). **c** Merapat trees with the characteristics of thick bark that enabled them to be fire resistant

of ground plants. The land affected by the severe fire had the bigger number of individuals compared to that affected by the moderate fire and the secondary forest (Fig. 3a). The species of the ground plants found in the affected land after the severe fire and without any vegetation cover were dominated by ferns. These ferns played an important role in forest ecosystem as well as in humus formation, and in protecting ground against erosion.

The causal factor of the big number of the ground plants in the land affected by the severe fire was the condition of the land that was still opened and the early phase of succession. Meanwhile, the secondary forest affected by the moderate fire had wide vegetation cover and it resulted in the suppression of the growth of the ground plants by other plants at the growth levels of seedlings, stake, pole and trees (Fig. 4).

Figure 2c illustrates the decrease in the density of the trees with the severity level of the fire. The more severe fire was, the lower density was. This was consistent with

D'Arcy and Page (2002) that the forest fire which affected the peatland in Central Kalimantan in 1997/1998 has caused 75% decrease in the density of the trees.

Shannon's diversity index at each of the growth levels of the vegetation was also more likely to decrease with the severity of the forest fire. According to Shannon, this was because the forest fire resulted on the loss of various species growing in the land. The index shows that the highest pole and trees were found in the secondary forest and classified into moderate diversity, while the index was low in the case of the forest fire in 2015.

The Characteristics of Soil After Forest Fire

The forest fire that affected peatland resulted in the environmental condition with more free air flow (aerob) than that in its natural condition, as such found in the peatland rarely affected by the fire and represented secondary forest. The more aerobe condition enable the change and the maturation of the peat materials which occurred in the peatland after the fire because of the high precipitation.

The compression has either reduced the volume of the peat mass (Dexter 2004) or increased its weight. Figure 5 illustrates the soil pores extant in the land after the severe fire with or without vegetation cover, which was denser compared to the other peatlands after the fire. The dense soil pores resulted in soil compression and ground solidifying and, hence, it led to the increase in the weight volume.

Based on the results of the study, the WHC values ranged from the lowest (162.59%) in the peatland after the severe fire and with vegetation cover to the highest (189.12%) in the secondary forest that were rarely affected by fire (Fig. 6) although they did not show significant difference. All of the WHC values were above 100%, which was consistent with the statement by Mutalib et al. (1992) that the water content of the peatland was in the range of 100–1300% of its dry weight.

The organic carbon content of the peatland after the fire was in the range of the lowest (77.04%) in the peatland after the severe fire and covered by vegetation to the highest (93.39%) in the secondary forest that was rarely affected by the fire (Fig. 6). The values tended to be higher compared to the range of the organic carbon of normal peatland, which was in the range of 54.3–57.84% (Barchia 2006). The high organic carbon content of the peatland after the fire without any vegetation cover might be influenced by the accumulation of organic materials in the land because of the transfer of the organic materials resulting from the burning process during the fire. Not only they came from the inside parts of the trees in the land, but also from the upper parts of the trees such as stems, branches and crown. In addition, the increase in the organic materials was also caused by the residue of the burning process whose main components included hemicellulose, cellulose and lignin that became carbon dioxide (CO_2) and carbonate (CO_3) compound. The CO_2 was released as gas, while the CO_3 would accumulate as ashes that the carbon content of the peatland increased (Lutz and Chanler in Iswanto 2005).

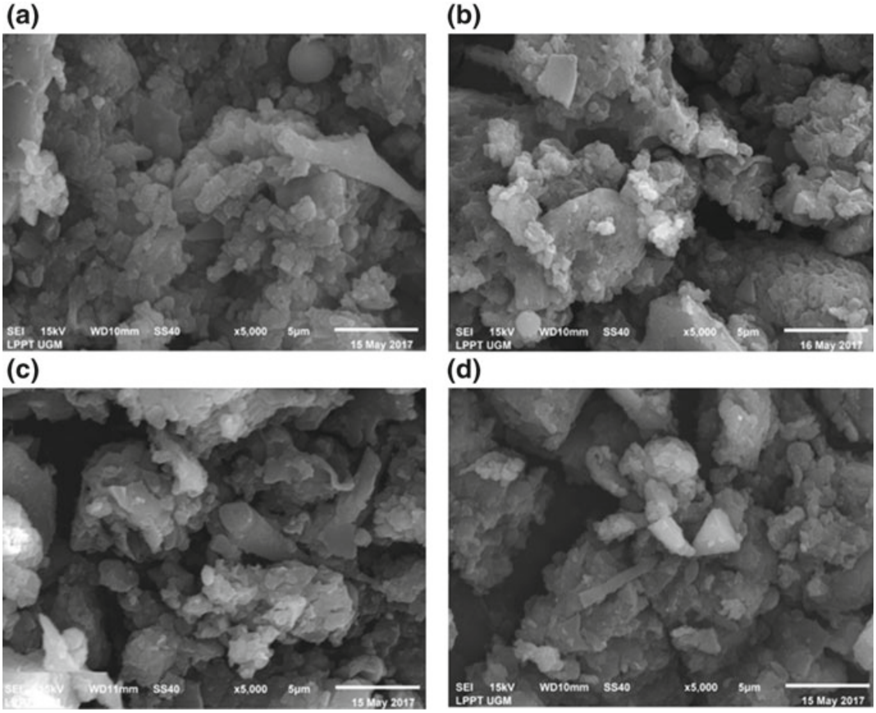

Fig. 5 The microscopic structure of the peatland after the fire observed using scanning electron microscope (SEM) at 5000× magnification. **a** The peatland after the severe fire without any vegetation cover (BT). **b** The peatland after the severe fire with vegetation cover (BA). **c** The peatland after the merate fire (BM). **d** Secondary forest (SF)

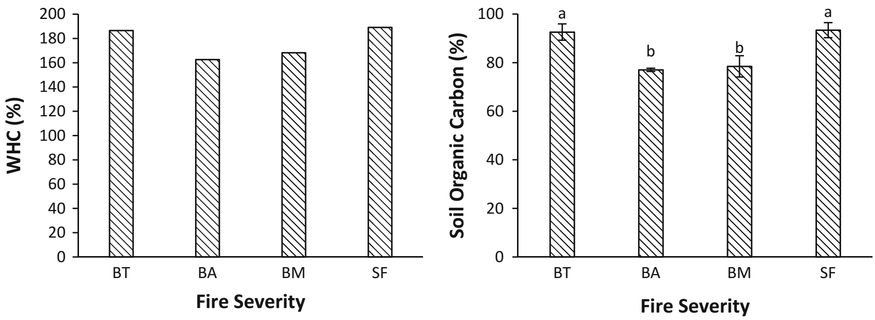

Fig. 6 The water holding capacity and the organic carbon at various severity of fire

The decrease in the organic carbon content of the peatland tended to happen in the land after the moderate fire and the land after the severe fire with vegetation cover (BA). This may be because the moderate fire happened only on the surface of the ground which did not cause massive damage as found in the land without any vegetation cover (Agus et al. 2004; Agus 2013, 2018).This could be proven that the remaining trees in the land affected by the moderate fire was 73.33%, while there was only 10% of the remaining trees in the severe fire without any vegetation cover.

The pH value of each of the peatlands was in the range of the lowest (3.27) to the highest (3.76). This corresponds with the statement by Noor (2010) that the majority of the peatland reacted from acid to very acid condition (pH < 4). The value was classified in ultra acid to extremely acid categories, while the mineral soil usually had the pH value of 5–8 (Barchia 2006). The mean pH of the peatland in the secondary forest was 3.27, meaning that it increased in the area affected by the moderate fire to 3.62 and in the area affected by the severe fire (BA) to 3.76. This shows that the forest fire caused the increase in the pH, hence, the availability of certain nutrients necessary for plants would exist and it would decrease again to normal in 5 years (Iswanto 2005). Therefore, if the pH was close to the initial pH, the availability of certain nutrients for plants was lower. Additionally, the increase in the soil pH was consistent with Chandler cit. in Sugato (2005) suggesting that the residue of the burning process could increase cation exchange, which tended to increase the soil pH.

The results of the analysis of scanning electron microscope with x-ray energy-dispersive spectroscopy (SEM-EDX) showed that the essential macro nutrients of the peatland after the fire were found in various types of soil. The essential macro element of Sulfur (S) was found only in the secondary forest, meanwhile, it was not found in the peatland after the moderate and severe fires in 2015. The causal factor of the loss of the sulfur might be the occurrence that took place a couple of years ago. According to Hoskin in De Bano et al. (1998) when the temperature of soil increased during the heating process, the soil chemical components contained in the organic materials would result in the loss of the organic materials at the temperature below 100 °C. While it would be easy for the elements to evaporate, it would disappear at the temperature of 200 °C. At the temperature of 200–300 °C, about 85% of the organic matters of the soil would disappear. At the temperature above 300 °C, the remaining organic matters with carbon content would disappear and the heating up of the temperature of 450 °C for 2 h or 500 °C, for half hour would cause the disappearance of 99% of organic matters.

Table 1 shows that the essential micro nutrients found in the peatland after the fire included Cu, Si and Zn. Copper (Cu) was the element found in all of the peatland after the fire. The causal factor of the presence of the Cu might be the presence of the chelating bonds between organic acid and the metals extant in soil (Stevenson 1982). Hodgson et al. in Mengel and Kirkby (1987) suggested that more than 98% of the Cu solution in the soil was stuck by organic matters.

The elements of the Zn and the Si represented the essential micro nutrients contained only in some areas of the peatland after the fire. The Zn was found only in the peatland after the severe fire and the land has been covered by vegetation and in secondary forest. Meanwhile, the Si was found only in the peatland after the moderate fire and without any vegetation cover. According to Barchia (2006) the minimum content of the essential micro nutrients was common in the peatland. Carbonate and phenol groups in the caution exchange site of the peatland could form complex bonds

Table 1 The percentage of the mass resulting from the electron dispersive X-ray (EDX) of the peatland at various severities of fire

Unsur	Mass (%)			
	BM	BA	SF	BT
C	50.27	55.3	50.78	51.34
N	15.89	17.56	15.05	16.44
O	30.38	25.47	30.03	30.62
Si	1.92	–	–	0.26
Cu	1.55	1.22	2	1.34
Zn	–	0.45	1.6	–
S	–	–	0.54	–

Note BT—Severely burned without any vegetation, BA—Severely burned with vegetation, BM—-Moderately burned, SF—Secondary forest

with micro elements that they were unavailable for plants. Moreover, the excessive reduction caused the change of the micro elements into their metal forms without any load (Andriesse 1988).

The forest fire that affected the peatland was the one that burned not only forest plants, but also the litters layer and part of the peat materials, especially those in upper layer (Usup et al. 2000). This caused the loss of a part of the upper layer of the peatland, which in turn caused the change in the environmental condition into more aerob because of the excessive drainage. Consequently, the peat materials were excessively exposed to air flow that resulted in the further change of the peat materials into more mature ones.

The graph showing the analysis results of the vegetation shows that there was not any secondary forest burned in 2015 with higher diversity index value at the growth levels of trees pole, stake and seedlings (Fig. 4). This shows that the forest fire caused the extinction of various species of flora and fauna (Purbowaseso 2004). Thus, the forest fire that affected the peatland had direct impact of the decrease in biodiversity along with its economic values. For example, the forest fire that affected the peatland in Central Kalimantan in 1997/1998 had burned the trees with high economic value such as ramin (*Gonystylus bancanus*) and belangeran (*Shorea blangeran*). In addition, it also caused 75% decrease in the density of the trees (D'Arcy and Page 2002). It was also responsible for the loss of 0.2–0.6 Gt of C and 35–70 cm peat layer (Page et al. 2002). The loss of the carbon had extraordinarily significant impact on the emission of the CO_2 into atmosphere. Meanwhile, the loosing rate of the peat layer was highly imbalanced with the formation rate and the accumulation of the peat materials relatively long time. The peatland grew at the growing rate of 0–3 mm/year. The growing rate of the peatland in Barambai Delta Pulau Petak, South Kalimantan was about 0.05 mm annually, while it was 0.13 mm/year in Pontianak. It went faster in Malaysia, which was about 0.22–0.48 mm annually (Noor 2010).

Conclusion

1. The forest fire that affected tropical peatland caused the decrease in the biodiversity of the vegetation as indicated by the decrease in Shanon-Whiener's diversity index and by the significant decrease in the number of the species, the density of the individuals of trees.
2. The physical and chemical characteristics of the peatland 2 years after the forest fire changed. It was clearly observed in the volume weight (VW) value, soil organic carbon, pH, available-N, available-K, and the presence of the essential micro elements of Cu, Zn, and Si. At the same time, the decrease in the water holding capacity (WHC), cation exchange capacity (CEC) and electric conductivity (EC) took place. However, the change in the chemical characteristics of the soil took place temporarily because of the loss of the nutrients resulting from the leaching, the emission into atmosphere accompanied by other negative impact of the disturbance of hydrological function, the loss of the carbon of the peat layers, as well as the increase in the temperature.

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Promoting Climate Agenda and Biodiversity Conservation at the Local Level: A Case for Nepal's Rural and Urban Municipalities

Krishna Roka

Abstract Nepal is one of the most vulnerable countries to climate change. This paper discusses the impact climate change is having on the biodiversity in Nepal and why local governments need to conserve biodiversity to act on a climate agenda in the coming years. It recommends ecosystem and landscape-based approaches for climate change mitigation, adaptation, and disaster reduction. Large-scale approaches can not only conserve biodiversity but also contribute to the social and economic well-being of local communities. Nepal has this unique opportunity to formulate and implement appropriate policies towards biodiversity conservation at the local level both in rural and urban areas. After 20 years of administrative governance, in 2017, Nepali people have elected new representatives for 264 urban municipalities and 480 rural municipalities. In addition, the newly elected local governments should increase their commitment for biodiversity conservation by involving local communities as stewards. To do that Nepal's rural and urban governments should develop policies that align with United Nations Sustainable Development Goals 11, 13 and 15 for making cities resilient and sustainable, combat climate change, and protect, restore and promote sustainable use of terrestrial ecosystems and halt biodiversity loss. To achieve them Nepal needs support from the international community to empower local people to monitor changes, to innovate for the future and adopt sustainability in their daily lives.

K. Roka (✉)
University of Wisconsin-Stevens Point, Wisconsin, USA
e-mail: kroka@uwsp.edu

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Background

Climate change is one of the most important socio-environmental issues today. The Intergovernmental Panel on Climate Change's (IPCC) fifth assessment is clear on the human influence on the climate system and the widespread impacts it has on human and natural systems (IPCC 2014a, b). IPCC with high confidence claims the following impacts of climate change on the natural system: terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to climate change. The report further identifies biodiversity conservation as one of the best options to mitigate further changes to the climate. Nepal, which is one of the most vulnerable countries to climate change, must create policies at the local and national level to promote climate agenda and biodiversity conservation. The policies should integrate adaptation and mitigation as complementary strategies for reducing and managing the risks of climate change (IPCC 2014a, b). Conservation of biodiversity will continue to provide the much-needed ecosystem services for the people and help to mitigate the impacts of climate change. Nepal has this unique opportunity to formulate and implement appropriate policies towards biodiversity conservation at the local level both in rural and urban areas. After 20 years of administrative governance, in 2017, Nepali people have elected new representatives for 264 urban municipalities and 480 rural municipalities.

For over five decades, Nepal's conservation programs operated under a top-down bureaucratic structure. The old approach is ill equipped to tackle the problems from climate change; therefore, this paper argues for a bottom-up nested approach where local people and their representatives are major actors. This is an opportunity for the local government to do planning and development activities to conserve existing biodiversity and promote climate change mitigation and adaptation. Without such policies, Nepal's vulnerability to climate change will increase from the high to the threatening level. This paper discusses the impact climate change is having on the biodiversity in Nepal and why local governments need to conserve biodiversity to act on a climate agenda in the coming years. It recommends ecosystem and landscape-based approaches to climate change mitigation, adaptation, and disaster reduction (Lo 2016). Large-scale approaches can not only conserve biodiversity but also contribute to the social and economic well-being of local communities.

In a communique to the United Nations, Nepal reported an increase in temperature and decrease in mean rainfall between 1975 and 2005. It also indicated that under various climate change scenarios, mean annual temperatures are projected to increase by 1.3–3.8 °C by 2060 and 1.8–5.8 °CC by 2090. Annual precipitation is projected to decrease by 10–20% during the same time (GoN 2016). Between 1977 and 2010 a 29% decrease in ice cover was recorded and the number of glacier lakes increased by 11%. Out of 75 districts, 29 are highly vulnerable to landslides, 22 to drought, 12 to glacier lake outburst floods (GLOF) and 9 to flooding (MoE 2010). Most of the impact from climate change is felt at the local level and therefore, local government is on the front lines of defense.

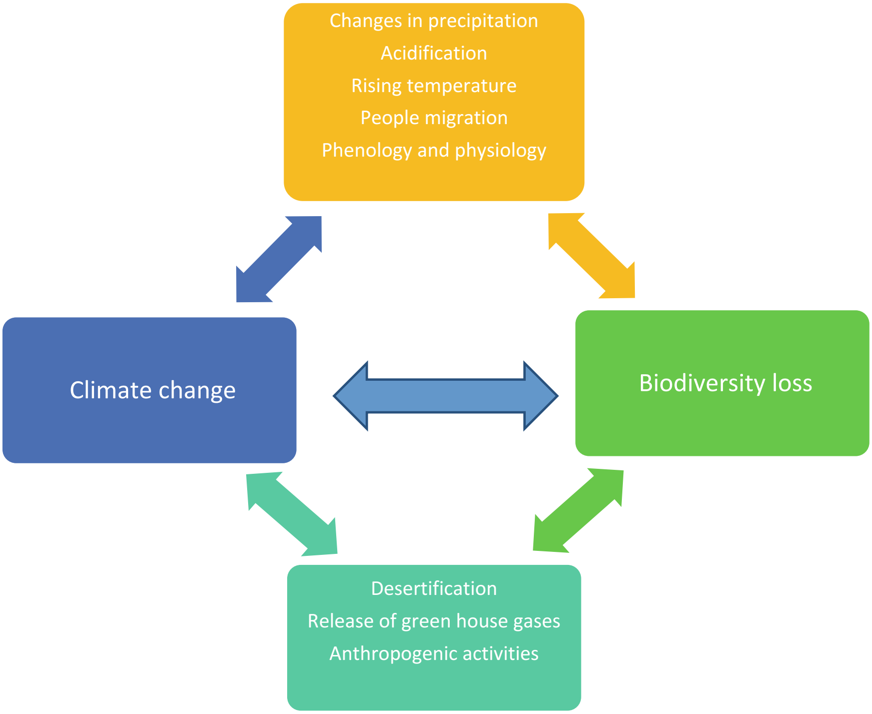

Fig. 1 Biodiversity and climate change

The focus on biodiversity conservation as a mitigation strategy is due to the fact agriculture, forestry, and other land uses account for about 24% of net global greenhouse gases (GHGs) (Baccini et al. 2015). In addition, the changes in land-use affect the economic system by adding extra cost towards mitigation and adaptation. The impact on the biodiversity well documented at all ecosystem levels from micro-biomes to large forests, which are experiencing profound changes, and some are even being pushed to the brink of extinction. Biodiversity conservation will not only protect further loss of species but also serve as a tool to mitigate future damage to the ecosystem. The inter-play between climate change and biodiversity loss creates a vicious cycle (Fig. 1) where climate change leads to biodiversity loss, which in turn leads to more climate change. Therefore, the only way to break this cycle is to improve biodiversity to create a different path towards sustainability by reducing climate change. To achieve these ends Nepal needs scientifically and socially feasible solutions. It is very crucial that such solutions operate in concert with local ecosystem and landscape for successful results. In addition, such strategies and policies could be aligned with the United Nations Sustainable Development Goals (SDGs), to which national and local governments are committed.

The focus of local governments on biodiversity conservation for climate change mitigation has to do with the relationship biodiversity has with many of the SDGs.

Here is one statement of how biodiversity conservation can help meet SDG 1—*End Poverty In All Its Forms Everywhere*,

> The conservation and sustainable use of biodiversity, including through sustainable agriculture based on ecosystem approaches, along with the restoration and safeguarding of ecosystems and the valuable services they provide, can help to prevent men and women from falling into poverty and can help to lift them out of it by increasing their income and reducing their vulnerability to external economic shocks or environmental disasters. (CBD 2017)

Indeed, biodiversity conservation is linked positively to all SDGs. Two other SDGs that relate directly to biodiversity conservation and climate change are SDG 11—*Take Urgent Action To Combat Climate Change And Its Impacts;* and SDC 15—*Protect, Restore And Promote Sustainable Use Of Terrestrial Ecosystems, Sustainably Manage Forests, Combat Desertification And Halt And Reverse Land Degradation And Halt Biodiversity Loss*. The interdisciplinary focus of the paper will contribute towards a better understanding of the relationship between climate change and biodiversity, and the rationale for the conservation of the latter. Some of the limitations of the paper include the lack of data on the impact of climate change on local biodiversity at the district or regional level, limited access to planning documents of local governments, and the lack of primary data on the priorities and perspectives of the newly elected local government officials.

Biodiversity in Nepal

Nepal is a land-locked country in south Asia between India in the south and China to the north. Nepal's physiography ranges from alluvial plains in the tropical lowlands to the snow covered Himalayan mountains. It is divided into five major physiographic zones extending east to west: the high himal, high mountains, middle mountains (middle hills), siwalik (*chure*) and terai (Table 1). IUCN identified 118 habitat types in Nepal, which support a rich biodiversity (IUCN 2015).

Nepal comprises less than 0.1% of earth's total land area, but it has significant biodiversity for its size. Nearly 3% of the world's known flora are found in Nepal

Table 1 Physiographic and bioclimatic zones of Nepal (GoN 2014)

Physiographic zone	Coverage (%)	Elevation (m)^2	Bioclimatic zone
High Himal	23	Above 5000	Nival (tundra and arctic)
High mountains	19	3000–5000	Subalpine and Alpine
Middle mountains	29	1000–3000	Subtropical and Montane (temperate)
Siwalik	15	500–1000	Tropical
Terai	14	Below 500	Tropical

Table 2 Nepal's Biodiversity, Government of Nepal (2014)

Group	Number of observed species	percent relative to known species worldwide
Angiosperms	6973	3.2
Gymnosperms	26	5.1
Pteridophytes	534	5.1
Bryophytes	1150	8.2
Lichens	465	2.3
Fungi	1822	2.6
Algae	1001	2.5
Flora total	11,971	–
Mammals	208	5.2
Birds	8673	9.5
Reptiles	123	1.9
Amphibians	117	2.5
Fish	230	1.9
Butterflies	651	3.7
Moths	3958	3.6
Spiders	175	0.4

(Table 2). Nepal has allocated some 23.4% for biodiversity conservation in the form of 12 national parks, 1 wildlife reserve and 6 conservation areas. However, nearly 83% of the country's forest lie outside the protected areas in the form of private forests and community forests (DFRS 2015). In addition, Nepal's agro-ecosystems and wetlands are rich in biodiversity that play a crucial role in the conservation and sustainable use of land. Around 550 crop species that have food value are under cultivation (MoFSC 2002). On the other hand, wetlands in Nepal support several threatened species of flora and fauna. Of the different geographical regions, the mid-hills contain the highest biodiversity where more than one-third of the forests lie (Mendez 2007).

Nepal's biological biodiversity is closely linked to the livelihood and economic well-being of many rural communities (Khatri 2010). It touches upon every aspect of Nepalese life, including agricultural productivity, food security, building materials, human health and nutrition, indigenous knowledge, gender equality, culture, climate, water resources and aesthetic value for society (GoN 2014). Therefore, any negative changes in the biodiversity will have moderate to severe adverse impact on the livelihood of these people. The nation's rich biodiversity is threatened by multiple anthropogenic and natural factors operating at different spatial scales (Bhattacharjee et al. 2017). Major threats include deforestation, biological invasion (invasive species), pollution, overexploitation, development of infrastructure, fire, and mining. Climate change is predicted to have profound impacts to the biodiversity in the future, particularly in the mountains. Poaching is responsible for decline of several large animals and some plant species; the high demand for wildlife products in the international market has put 43 bird species and large mammals like rhino (*Rhinoceros unicornis*), tiger (*Panthera tigris tigris*), musk deer (*Moschus chrysogaster*), pangolin (*Manis* sp.) under risk from poaching (GoN 2014). In response, the national government and NGOs are actively involved in managing and preserving the natural resource heritage.

In recent years, conservation efforts by the national government, NGOs, INGOs, and local communities have increased forest cover; however, the gains are not equally distributed. For example, in 2015 the government reported an increase in forest cover of 40%, up from 29% in 1998 (DFRS 1999, 2015). In the Chitwan-Annapurna Landscape (CHAL) of central Nepal the forest area remained unchanged (35.5%) between 1990 and 2010 (WWF 2013), whereas forest area declined by 9% in the Kailash Sacred Landscape (KSL) from 1990 to 2009 (Uddin et al. 2015). Without robust policies and planning, forest loss across the country are projected to intensify in the future. The role of policymakers and newly elected local leaders has never been so crucial to conserve biodiversity in Nepal.

Politics play a large role in Nepal's natural resource management policies. Forests are a fertile ground for exploitation by politicians seeking votes; as a result, in past years the country lost significant area of forests to resettlement and associated activities often with hidden political agendas. Nepal cannot afford to lose more forest resources (Khatri 2010). Therefore, it is important to inform and assist policy makers on the environmental and economic benefits of forest conservation. Nepal is a global leader of participatory forest management, which can be a conduit for a successful climate change mitigation system.

Climate Change and Nepal

Nepal's unique physiographic and topographic features give rise to its climatic and ecological diversity. The climate ranges from subtropical in the south (terai) to arctic in the north (high himal). Around 80% of the precipitation in Nepal occurs during the Indian summer monsoon (June–September). The mean precipitation is about 1530 mm, with maximum precipitation occurring in the siwalik and middle mountains, and the high mountain range receiving less rain. The temperature is highest during the summer (May–June) in the 36–39 °C range and the winter temperature minimum averages −3 °C. However, the temperature variability depends on the elevation. The terai region is the warmest part of the country, with high temperatures exceeding 40 °C (Chalise et al. 1996).

Nepal is one of the most vulnerable countries to climate change (IPCC 2007). Climate change will bring variations in precipitation and increase in temperature that will affect glacial and snowpack melting. Both processes will have potentially severe socio-environmental consequences as they affect the availability of freshwater to millions of people and influence species distribution and survival. WWF Nepal reported in 2017:

> Climate change has hit Nepal hard, and it has hit fast. It is causing greater variations in weather patterns and more extreme weather events, like the drought that contributed to the exceptional number of wildfires that raged across Nepal during 2016's pre-monsoon season. But the fires are just one small piece of the shifting climate-change picture. The rains, too, have become less predictable, making it more difficult to decide which crops to grow and when to plant them. More hailstorms and stronger snows in some areas are affecting agriculture as well. (Seiff 2017)

IPCC's fourth assessment report projected a temperature rise of 2–4 °C in South Asia by the end of the century. It also reported an increase in GHGs in the region mostly from anthropogenic activities. This increase in GHGs will cause further warming and long lasting, possibly, irreversible impacts to the people and the ecosystems. The fifth assessment however projects some reductions in global emissions after 2020 which would keep the warming below 2 °C in the region (IPCC 2014a). Nepal's high-altitude regions have seen more warming in recent years than the low-lying regions (Thapa et al. 2016). According to the government, the average annual warming between 1971 and 2014 was 0.056 °C. The biggest change has been recorded in the precipitation level. Droughts have become more intense in the central region since the 1980s, and the mean rainfall during the monsoon season has increased from 1981 to 2012 (Jeeban et al. 2015). In the same time rainfall in other seasons decreased by 1%.

Climate Change Impacts on Biodiversity in Nepal

Worldwide numerous studies have observed the impact of climate change on biodiversity. Some of the responses from species to climate change include changing their phenology events like blooming, migration and breeding (Parmesan and Matthews 2005; Bellard et al. 2012). The impact could happen at the species level where it will affect the synchrony with species' food and habitat requirement (Bellard et al. 2012). At the ecosystem level, it could affect vegetation communities and even alter their composition. At higher altitude, species are expected to expand northwards and shift their tree lines upwards at the expense of low stature tundra and alpine communities (Alo and Wang 2008). Because of climate change several species are altering their range, mostly at higher altitudes (Tingley et al. 2012), while some harmful pathogens are causing alarming declines in amphibian populations at lower altitudes (Bosch et al. 2007). One of the most extremes outcome of unchecked climate change is species extinction (Bellard et al. 2012).

The knowledge on the impacts of climate change on Nepal's biodiversity is limited. Some of the known consequences listed by the national government are, (i) shifts in agro-ecological zones, prolonged dry spells, and higher incidences of pests and diseases, (ii) increased temperature and rainfall variability, (iii) increased emergence and quickened spread of invasive alien plant species, (iv) increased incidence of forest fire in recent years, (v) changes in phenological cycles of tree species, (vi) shifting of treeline in the Himalaya, and (vii) depletion of wetlands. However, available research finding on the impact of climate change on individual plant and animal species is more pronounced, and indicate the need for immediate actions.

Studies on the impact of climate change on forests in Nepal are related to altitude variations (Thapa et al. 2016). Climate projection show lower and mid-montane forests are more vulnerable than upper montane and subalpine forests. The low and mid-montane forests are predicted to decrease in size into small patches of microrefugia and may act as "climate corridors" for species forced to shift northwards, while the subalpine scrub vegetation continues to shift range northwards (Thapa et al. 2016). Other notable alterations in forests in the Himalayas include early average onset of the growing season and increased length of the growing season. In western Himalayas, researchers have found an overall longer growing season, while little variation was recorded in central and eastern Himalayas (Shrestha et al. 2012). At the species level, several alpine plant species exhibited distribution differences under current climate conditions versus future scenarios. Many species are projected to shift northwards and shrink in overall distribution under future climate scenarios (Song et al. 2004). Himalayan fir (*Abies spectabilis*) responded negatively to temperature rise with slow growth rate and its tree line extending northwards in response to climate change (Gaire et al. 2011). For some species like the Chinese caterpillar fungus (*Ophiocordyceps sinensis*), a potential loss of habitat and possible range extension are predicted for the future (Shrestha and Bawa 2014). As forests support biodiversity and ecosystem services to local communities, changes in the forest ecosystem can prove catastrophic to humans and animals.

Negative effects of climate change on several species of animals are also predicted. Most of the impact will be in their distribution and loss of habitat from changing precipitation and rising temperature. For example, a 30% loss of habitat is predicted for snow leopard (*Panther uncia*) mainly along the southern distribution range due to the projected shrinking of the alpine zones (Forrest et al. 2012). A population extirpation risk is predicted for several species of salamanders and frogs with changing precipitation levels (McCain and Colwell 2011). Distribution of invertebrate species were found to be significantly related to altitude variation in the central Himalayas. Of the 78 species studied, 79% exhibited a negative response to increasing altitude, which is predicted to occur in the future (Shah et al. 2015).

All future scenarios under the current climate condition predict significant impact to Nepal's biodiversity. In addition to the direct impact to the native species, climate change could assist in the expansion and distribution of invasive species, which would outcompete with the native flora and fauna.

Nearly 75% of Nepal's population depend on agriculture, which is highly climate sensitive and increasingly at risk from climate change impacts (CDKN 2017). Key effects of climate change on agriculture include declining water availability for irrigation, increasing peak flood flows, changing river morphology and declining crop yields (at higher altitudes) (Pradhan 2017). The projected changes from climate change will exacerbate the existing harmful impacts in the agriculture sector. It is expected an increase in dryness in drought-prone areas and wetter conditions in wet areas where plant species may not adapt to the new production conditions. On the other hand, temperature increase means crops like rice and wheat can be grown in higher altitudes (Gautam 2008). A 4 °C increase in temperature would lead to increase in rice yield in the terai by 3.4%, in the hills by 17.9% and in the mountains 36.1%. At the same time, climate change can delay crop maturity and destroy local species. Climate change will also affect livestock in higher altitudes that are essential to people's livelihood. Resident of Mustang (a high-altitude district) reported increased prevalence of new livestock diseases, increase in mortality, decrease in animal breeding behavior, and decrease in animal productivity (Koirala and Shrestha 2014). At higher altitude, climate change associated temperature changes has resulted in less snowfall and rapid melting of snow, which in turn caused less water in the upper part of the region, lower ground water discharge, less grass production, weaker agricultural production, and a changing ecosystem (Aryal et al. 2014).

Nepal's forests are an integral part of what is essentially an agrarian society. For example, forest litter and livestock manure are the main source of fertilizer, and fuelwood is the main energy source for 70% of the population. Climate change will not only affect forest biodiversity but also the livelihood of millions of people who depend on the biodiversity. According to the government of Nepal, the likely impact of climate change on biodiversity can be categorized into three likely scenarios (GoN 2014):

(a) The climatic range of many species will move upward in elevation from their current locations. This will have differential effects on species. Some species will migrate through fragmented landscapes whilst others may not be able to do so.

(b) Many species that are already vulnerable are likely to become extinct. Species with limited climatic ranges and/or with limited geographical opportunities (e.g., mountain top species), species with restricted habitat requirements, and/or small populations are typically the most vulnerable.

(c) Changes in the frequency, intensity, extent, and locations of climatically and non-climatically induced disturbances will affect how and at what rate the existing ecosystems will be replaced by new plant and animal assemblages.

The High Himal and High Mountain areas are likely to experience the largest transformations. Among the natural habitats, remnant native grasslands are highly vulnerable to the impacts of climate change (Koirala and Shrestha 2014). The threats to biodiversity are affected by several underlying social, political, economic, technological and cultural variables that also contribute to climate change. According to the national government, the growth of population, along with changing density and distribution patterns, are believed to have contributed to loss and degradation of forest habitats in different ways, including increased forest encroachment for agricultural expansions and increased pressure to meet energy and timber needs (GoN 2014). Therefore, policies towards biodiversity conservation under the climate change predictions are key to prevent further loss of biodiversity in Nepal. These policies should be part of the local government's priority in the coming years.

Climate Agenda and Biodiversity Conservation at the Local Level

According to the IPCC, mitigation and adaptation are complementary approaches for reducing risks of climate change impacts over different time-scales (IPCC 2007). Mitigation will reduce climate change impacts in the short and long-term, adaptation will reduce the vulnerability of people and ecosystems to future changes. Local governments can play a significant role in planning and implementing mitigation and adaptation strategies in coordination with the national government, as the IPCC stated:

> National governments play key roles in adaptation planning and implementation through coordinating actions and providing frameworks and support. While local government and the private sector have different functions, which vary regionally, they are increasingly recognized as critical to progress in adaptation given their roles in scaling up adaptation of communities, households, and civil society and in managing risk information and financing. (IPCC Fourth Assessment 4.4.2.1, 2007)

At the national level, Nepal has made climate change an important topic and developed adaptation and preparation plans to adapt and mitigate climate change. A high-level Climate Change Council under the Prime Minster was formed in 2009 to guide climate change adaptation and mitigation. In 2008, the government also created the National Adaptation Programme of Action (NAPA) to prioritize community based coping strategies for climate-induced vulnerability. In addition, Nepal has taken several initiatives to reduce climate hazards and build resilience. Nepal's communique to the UNFCC includes a detailed list of actions and strategies the government is planning to implement as agreed under the Paris Agreement of 2015. Such plans often appear great on paper but poor on implementation. The first step towards biodiversity conservation under the future climate scenario is to close the gaps within the current conservation system. Nepal became part of the Convention on Biological Diversity in 1994; however, it failed to enact comprehensive legislation for conservation of biodiversity and sustainable use.

The current policies on environment, development, and local governance lack clear objectives on biodiversity conservation. For example, the Agriculture sector's overemphasis on commercialization may undermine biodiversity management (GoN 2014). Many of the laws at various levels are not well connected and coordinated and often contradict each other. The Forest Act of 1993 and the Local Self-Governance Act of 1999 differ on how the revenue from the sale of forest products should be distributed. The Forest Act states local user groups can manage the revenue independently; on the other hand, the Self-Governance Act stipulates the revenue should go into the district fund. It is clear Nepal's well-intentioned policies and strategies for biodiversity conservation are marred by implementation and evaluation difficulties. Therefore, the newly elected local governments should prioritize biodiversity conservation into all development and planning programs. Some of the agendas may require improvising the existing management system, like the community forestry program, while other frameworks must be implemented or tested to mitigate further impact from climate change.

Models of Adaptive Management

Designing a climate change strategy for the future is riddled with uncertainty; however, inaction is not an option. Climate change adaptation is a way to modify strategies to persist and succeed under new and changing climate conditions (Abrahms et al. 2017). This paper focuses on the ecosystem-based adaptation similar to IPCC's definition, "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects" (IPCC 2007). One way to build a strategy is by using local scenario planning, which creates multiple plausible futures to evaluate the outcomes and consequences of different decisions (Peterson et al. 2003). Several adaptive management frameworks for ecosystems are available; this paper recommends three frameworks (adopted from Abrahms et al. 2017) that are pertinent to Nepal's biodiversity.

(a) Adaptation for conservation targets (ACT) framework—The ACT framework offers a structured approach to specific adaptation action (species/ecosystem) and has been implemented across North America. It includes six steps to climate change adaptation: (1) identify the conservation feature of interest and define conservation objectives, (2) build a conceptual model to assess impacts of possible future scenarios, (3) identify management options, (4) prioritize actions, (5) implement actions, and (6) monitor and evaluate outcomes.

(b) Climate-smart conservation (CSC) framework—This offers a structured approach to integrate climate-change adaptation into existing planning processes. The CSC framework consists of seven steps: (1) define conservation objectives, (2) identify key climate vulnerabilities, (3) revise objectives as necessary, (4) identify management options, (5) prioritize actions, (6) implement actions, and (7) monitor and evaluate outcomes.

(c) Portfolio decision analysis (PDA) framework—The PDA framework offers a quantitative approach to selecting a portfolio for management actions where there is a trade-off between human activities and biodiversity conservation. Its purpose is to maximize natural assets while minimizing impacts to human assets. It also includes six steps: (1) identify natural and human assets of interest, (2) determine vulnerabilities of and risks to assets, (3) identify potential management actions, (4) quantify the 'effectiveness' value of management actions, (5) determine costs of management actions, and (6) determine an optimal set of management actions given costs and budget constraints.

Nepal has already achieved success in the management and conservation of biodiversity by integrating social, economic and environmental values in its policies. Nepal's conservation policies have transformed from 'people exclusionary' and 'species focused' towards 'people-centered and community based' in recent years (DNPWC 2017). The government of Nepal amended its National Park and Wildlife Conservation Act of 1973 to allocate 30–50% of the total revenue from parks and conservation areas into local community development. Communities, local authorities, and civil society organizations are now directly involved in various activities to promote integrated and long-term conservation management. To manage the protected areas, the government of Nepal has collaborated with international organizations like the International Union for Conservation of Nature (IUCN) and the World Wildlife Fund (WWF). In the global platform, Nepal is a party and or a signatory to international treaties like Convention on Biological Diversity (CBD), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Global Tiger Fund (GTF), Ramsar, South Asia Wildlife Enforcement Network (SAWEN), United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Convention (DNPWC 2017). The community forestry program has proven effective in mitigating climate change by sequestrating carbon and in regulating weather patterns (Pandey et al. 2016; Khanal et al. 2017). The community forestry program's success suggests that any conservation efforts in Nepal should be integrated with the people's livelihood. Promoting biodiversity conservation in the agriculture sector can be effective in emulating participatory conservation outside the forestry sector.

Since agriculture is the mainstay for majority of the Nepalese, this sector should be protected from the adverse impacts of climate change. To do that the government policies should integrate agro-biodiversity into its planning and assist farmers with technical and financial resources to continue producing food for the future. Additional benefits of agro-biodiversity and agro-ecosystems will help with climate change mitigation, biodiversity conservation, and water conservation.

At the local level, this requires farmers participation in the decision-making process. Improving current practices of in situ conservation of crop and livestock genetic resources, using local seeds and research and promotion of adaptive traits of local crops are ways to help farmers. It is crucial to make usable knowledge accessible to farmers, make policies more sensitive to smallholder farmers, and create incentives for private sector to promote climate-smart agriculture (Poudel 2017). The climate-smart agriculture approach can be used to increase ecological diversity by helping farmers to plant new crops and seeds, build home garden, practice mixed farming, establish community seed banks, and multi-use water systems (Poudel et al. 2017). Other local level strategies include planting native grass, constructing water holes, rainwater harvesting and monitoring of distribution and shift of trees (Aryal et al. 2014). These activities will not only sustain livelihood options but also conserve biodiversity.

Managing biodiversity under climate change is challenging for a poor country like Nepal. One of the biggest obstacles to Nepal's climate agenda is funding. Currently, nearly 55% of the total climate change expenditure comes from donor support (Nepal 2012). Even though the national government has increased the budget for climate change, it is only 10.34% of the total budget. Of the different programs, nearly 45% of the climate change expenses were allocated for forests and biodiversity conservation (Oxfam 2014). These programs are already having an impact on climate change adaptation and mitigation as evident a recent project.

Success Story: Hariyo Ban Project

In August 2011, WWF Nepal initiated one of the largest, most complex conservation, development and climate change projects in the country (Seiff 2017). Hariyo Ban (green forest), a $40 million project funded by the USAID was implemented in partnership with CARE, the Federation of Community Forest Users Nepal, and the National Trust for Nature Conservation. It was designed at the landscape-level as a community-driven approach to conserving biodiversity and assisting people to adapt to climate change and mitigate greenhouse gas emissions by storing carbon. It covered two major landscapes: the Chitwan-Annapurna Landscape (CHAL) and Terai Arc Landscape (TAL). Initial assessment by WWF found the CHAL was more vulnerable to climate change and people in the area suffered from landslides, crop failures and changes in rainfall patterns. For five years, the Hariyo Ban worked with thousands of local people and Nepal's government to mitigate climate change. It claims to have sequestrated an estimated 3.7 million tons of carbon emissions in the forests (Netra Sharma, USAID).

The success of the project is visible from the size of the land area conserved, the climate change adaptation activities undertaken, and biodiversity conservation achieved (Table 3). The project's success offers hope for Nepal to come out from being one of the most vulnerable nations to a successful example of mitigation and adaptation to climate change. As one participant in the project said, "before Hariyo Ban, the forest was very thin, after we started to take care of the forest, conservation improved, and the forest has become denser." The chief operating officer of WWF, Marcia Marsh, summed up the project's success as being both social and environmental.

Biodiversity conservation is a multipurpose objective. It can serve as a buffer during extreme climate and weather events like rainfalls, droughts, storms, and landslides. Conservation of resilient and disease resistant plants, livestock breeds, and fish will tackle food insecurity and empower local communities. Promoting agrobiodiversity will foster soil microorganisms and maintain soil's physical and ecological health, ultimately improving soil fertility. Integrating biodiversity conservation in urban planning will contribute to sustainable human settlements. Even in urban areas, healthy ecosystems can provide protection and resilience from extreme weather events and disasters (CBD 2017). Overall, ecosystem-based approaches contribute to all SDGs to achieve social, economic and environmental targets. Specifically, biodiversity conservation is key to mitigation and adaptation efforts for countries like Nepal. This will also fulfill Nepal's commitment to climate change at the global level.

Table 3 Hariyo Ban's success in numbers (Seiff 2017)

Biodiversity conservation	Sustainable landscapes	Climate change adaptation
1. **61,244** people benefiting from economic activities including skills training, agriculture, and green enterprises like beekeeping, growing broom grass, and cardamom plantations 2. **201** community-based antipoaching units established and mobilized 3. **32,727** members of community natural resource management groups engaged in biodiversity conservation 4. **131.7** miles of electric fencing erected to reduce human-wildlife conflict 5. **485** community learning and action centers established or strengthened to increase participation 6. **18** key plant and animal species benefiting from increased research, monitoring, and conservation efforts	1. **167,807** acres restored through improved wetland and grassland management, and fencing to control livestock 2. **7136** acres of new forest plantations 3. **2** payments for ecosystem services projects implemented in the Phewa and Marshyangdi water catchments 4. **10** policy documents on forest management and products, biodiversity, and climate mitigation supported by Hariyo Ban 5. **147,375** people benefiting from alternative energy sources. This includes: 6. **18,929** improved cookstoves 7. **6143** biogas units	1. **18,392** people trained in climate change adaptation strategies 2. **421** climate adaptation plans prepared activities supported under these plans include: 3. **359** drinking water supply systems installed and/or maintained 4. **156** irrigation systems installed/and or maintained 5. **85** miles of foot trails maintained 6. **81** wildlife watering holes maintained 7. **414** check dams, dykes, and embankments constructed 8. **367,407** people with increased awareness of, capacity for, and/or participation in adaptation activities

> Ecosystems such as forests, rangelands, croplands, peatlands and wetlands represent globally significant carbon stores. Their conservation, restoration and sustainable use is included as a part of many Intended Nationally Determined Contributions, and is therefore a critical element for the fulfilment of the Paris Agreement under the United Nations Framework Convention for Climate Change, a global commitment toward the mitigation of dangerous changes to the Earth's atmospheric temperature and climate system. (CBD 2017)

Implementing the climate agenda for biodiversity and INDCs objectives in Nepal faces many challenges. First, there is a dearth of capacity at all levels of the bureaucracy that does not understand how potentially detrimental the impacts of climate change would be on the economy. Second, the heavy dependence on subsistence agriculture puts many farmers at risks from small changes (both positive and negative) in the environment. Third, the topography presents challenges for potential adaptation process. The isolation created by the geography affects mobilization of resources and technology for adaptation and mitigation. Fourth, rapid urbanization has pushed the government to the brink to fulfill the needs of the people. Furthermore, urban expansion into ecological sites and pressure on the local environment impose newer challenges to adaptation. Fifth, a history of institutional failures and political instability, both at the national and local level, will hinder effective adaptation and implementation of policies. This has led to high turnover of government staff, reorganization of public institutions, and ineffective coordination and collaboration among political parties and interest groups. Sixth, climate change and biodiversity conservation have not been an issue during elections. Only three parties had included climate change in their manifesto and development associated activities like construction and production dominated the manifesto of all political parties in the local election of 2017. To overcome the above challenges, this paper proposes the local government play a larger role in creating locally feasible adaptation and mitigation plans for climate change. Biodiversity conservation should be an integral component of all plans as it is the cost-effective strategy that is already widely practiced and has produced successful results on climate change. Therefore, the paper recommends the following to the local governments of Nepal:

(1) Address the impacts of climate change on biodiversity by investing on timely actions to reduce further biodiversity loss;
(2) Plan and implement ecosystem-based approaches to tackle current and future climate change impacts;
(3) Develop education and awareness programs for the public on the importance of biodiversity for climate change adaptation, mitigation and disaster risk reduction;
(4) Recognize the role of protected and conservation areas in climate change adaptation, mitigation and disaster risk reduction;
(5) Promote ecosystem-based approaches in rural and urban areas;
(6) Use existing tools and techniques to enhance ecosystem-based approaches and, where necessary, refine these tools and techniques; and
(7) Ensure climate change adaptation, mitigation and disaster risk reduction activities include indigenous and local knowledge and benefits them.

Conclusion

The main objective of this paper was to discuss the relationship between climate change and biodiversity in Nepal, and how local governments can mitigate some of the impacts by integrating biodiversity conservation in their governance. Under the current and future scenario, climate change will have immeasurable impacts on Nepal's biodiversity. Ecosystems and communities at higher elevations will be most affected from environmental change. This gives the newly elected local governments a window of opportunity to develop and implement policies that will promote biodiversity conservation and tackle climate change. The focus on governance is important as past and existing policies to tackle climate change were poorly implemented. In addition, good governance is fundamental to make progress in adapting to climate change and mitigate its impacts. The newly elected local government offers excellent opportunity to carve a path towards a future where economic, social and environmental values are equally considered. The paper focused on one of the many ways to mitigate climate change- promoting biodiversity conservation. Furthermore, Nepal can use its experience with participatory resource governance towards climate change mitigation and adoption. The paper offers the following prospects for the future: capacity building of local governments, integrating relevant SDGs in local planning, strengthening collaboration between local and national government for biodiversity conservation, and seeking international support to design and implement conservation programs for climate change mitigation and adaptation.

There are ample policies and strategies developed by the government, NGOs and INGOs to address climate change in Nepal. However, translating those policies into tangible actions with funding and skilled human resources is a challenge (Poudel 2017). Failing to implement a successful mitigation strategy would affect achievement of other objectives related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development (IPCC 2014a, b). Importantly, biodiversity conservation will assist Nepal to achieve its SDGs. Therefore, increasing efforts to mitigate and adapt to climate change implies a concerted effort through interactions and connections among human health, water, energy, land use, and biodiversity. To do this the national and local governments could collaborate with the many bilateral and multilateral organizations working in Nepal, and connect with the international community. Not acting to mitigate climate change would irreversibly damage the ecosystem of Nepal.

Nepal is already a leader in participatory conservation practices. The community forestry program's success in restoring forests should be applied towards climate change mitigation and biodiversity conservation. The diversification of participatory practices will conserve species and support livelihoods. As the senior climate change expert with the WWF said, "you can't do good conservation, without learning from the people who live there and helping meet their needs" (Seiff 2017). Future conservation practices need public participation in urban and rural areas. The rapid urbanization in Nepal could result in an increase in GHGs through consumption and land conversion; therefore, the future cities should be sustainable with lots of green spaces, biodiversity refuges, and powered by renewable energy. Climate change, therefore, offers an opportunity for the local governments to commit to biodiversity conservation and make Nepal an example of successful of climate change mitigation and adaptation in the region or probably in the world.

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Climate and Biological Diversity: How Should the Effects of Climate Change on Biological Diversity Be Legally Addressed in International and Comparative Law and Solutions?

Sergio Peña-Neira

Abstract International treaties and declarations on climate change have focused almost exclusively on sources of climate change neglectfully the consequences on biodiversity the ultimate foundation for life on Earth. Although extremely appropriate, such approach neglect to the consequences of climate change on biological diversity and on their components (animals, plants, insects, microorganisms and habitats) almost condemned to disappear due their impossibility to move or adapt. Therefore, a lack of legal rules in international law has arisen due to lack of international legal framework to address loss biodiversity by conserving it in a mixture of forms of conservation. An example is reflected in "climate change and the law" a report of the Argentine Association of Comparative Law to the XVIII Congress of the International Academy of Comparative Law (author Professor Erkki Hollo). In this report, consequence of climate change on the biological diversity has not been addressed due to lack of legal rules (among other reasons). Sustaining agriculture and agrobiodiversity to maintain food production for human beings is part of the "ecosystem services" of biodiversity that have been completely forgotten when the consequences of climate change has not been properly addressed. In order to fill scientific gap grounds from natural science and juridical sciences particularly, international law will be explained in this article arguing for preventive measures to save biodiversity in danger. It is a conceptual paper as most of our work in sciences. First the paper will establish not only the relationship between n the effects

S. Peña-Neira (✉)
Society and Health Research Centre—Facultad de Humanidades, Universida Mayor (Chile), Campus Alonso de Córdova, Badajoz 130 of 1403, Las Condes, Santiago, Chile
e-mail: sergio.penaneira@gmail.com; sergio.pena@umayor.cl; sp898@cam.ac.uk

S. Peña-Neira
University of Cambridge, Brandon Research Fellow, Lauterpacht Research Center for International Law, 5 Cranmer Rd, Cambridge CB3 9BL, UK

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of climate change on biodiversity for legal scholars but solutions to the problem will be discussed. Most of the literature on the subject seems to lack the importance of international law and public policy on facing the aforementioned problem and it is not possible to "act" without legal rules.

Introduction

Focusing on destruction of biodiversity due to consequences of changes in climate by a lack of legal rules is basic because knowing legal solutions against destruction of biodiversity by climate change might be a contribution to prevent such annihilation. Reasons for such lack are not clear but maintaining such lack of legal rules might be extremely costly due to biodiversity loss including unknown species and their "ecosystem services".

Lambers has depicted in a serial of warrants this problem: "Move, adapt or perish. (…) Species may face extinction if habitat sizes shrink (for example, at the pole or at mountain points) (…), or if immigration barriers (D) or limited dispersal ability (…) prevent them from reaching newly suitable habitat" (Lambers Ris 2015). In certain cases, some species are "migrating" to other places. However, such a migration should be under help of law by promoting conservation of species or allowing movement of members of these species (Hurlbert 2015; Araújo 2015) or encouraging movement of biodiversity by human beings to conserve it in different but safer places. A procedure of interpretation of current legal rules or enactment of international legal rules are basic forms of solving a lack of rules.

Certainly, biodiversity plays a key role on giving human beings quality of life. The reasons for prevention and content of effects of climate change on biodiversity is that a large amount of our needs as specie is intimate related to biodiversity and it is possible to human beings to adapt to the effects of climate change but is uncertain for biodiversity itself. Without such adaptation, most probably, biodiversity will perish and as human beings, we will not be able to sustain the needs of food of an ever-increasing population. Further, it is necessary to establish not only the connection in international legal rules but to define certain basic possibilities for solving the legal gap. What it is much more important, connections between climate change and biodiversity has been addressed since the 1960s (e.g. Rachel Carson's books silent spring, to mention one of many titles) (Carson 1962) but we have not been able to consider such relationship together. Supposedly this was the basic feature, the basic rationale behind both aforementioned international treaties and considering the book of Carson this should be the main focus of international research but still there is not transdisciplinary and interdisciplinary research on climate change. This article might be a first step not only to discuss the topic but to propose certain solutions, legally, and of course, in public policy aiming to consider further research from natural scientists.

Some solutions seems to be impossible, for example: (1) biodiversity corridors (however, they would create international troubles as well as national one related to problems of speed of biodiversity and capacity to define places in which this diversity might have opportunity to survive. The problem is not only at species level but at ecosystems, habitats and other levels). (2) Our proposal is a combination on what has been the rule of law established in the Convention on Biological Diversity, conservation ex situ and in situ (Articles 7 and 8). In other words, a change of habitats, ecosystems and species from one place to another place considering information from natural science. However, international environmental governance (Galaz et al. 2012) still has not solved this issue, for example Conventions on Biological Diversity and on Climate Change and even the recent Paris Agreement has not addressed the problem.

(I) Conventions

In general terms legal norms expresses policy on a subject. As far as biodiversity and climate change are concerned, international policy has been expressed by large groups of States in international legal rules: conventions on biological diversity and climate change.

The Convention on Biological Diversity (ONU 1992a) aims conservation of genetic resources by establishing conservation or ex situ or in situ in articles 8 and 9 of this treaty (ONU 1992a). On the other hand, the Framework Convention on Climate Change (ONU 1992b) has not addressed the effects of climate change on biodiversity. Even recent convention, the Paris Agreement has included international rights and obligations on the subject and only a reference has been placed in paragraph 14th of the Preamble (ONU 2015). However, the Convention on Biological Diversity has included an article generating a solution based on interpretation of international legal rules. Article 22 expressly prevent conflicts with rights and obligations stated in other treaties unless exercising them might bring negative consequences for biodiversity (ONU 1992a). Negative consequences like disappearance or great damage for biodiversity would be possible, therefore a common interpretation in which not only sources for climate change should be addressed but consequences too.

(II) Lack of Legal Rules on Conservation Vis a Vis Effects of Change of Climate

As pointed out already, the Convention on Biological Diversity (ONU 1992a) and the Framework Convention on Climate Change (ONU 1992b) have different aims. We will call them “static”. They rule or conservation, sustainable use or utilization of genes’ from individual in species and even conservation of individuals and species as well as their technological change (ONU 1992a) or sources of the effects of the change of climate. They were not established to address in a proper way consequences for biodiversity arising from effects of the change of climate and other sources.

In 1992 rules in both conventions were considered sufficient to solve the problem (Conserving genetic resources and biodiversity and diminishing CO_2): a clear application internationally and nationally of both conventions would diminish negative effects of climate change on biodiversity. Even internationally such combination of conventions have not been considered properly and it is far from solving such problem.

The lack of legal rule is based on change of conditions as consequence of climate change and the need of new sites of individuals or species and even ecosystems.

As already pointed out, one pressing problem is disappearance of natural habitats of individuals, species or ecosystems due to climate change effects'. Therefore, such change might be developed on individuals' or species' own decision based on detection of negative effects of change of climate and promoting such behaviour. Such movement might be developed with or without help of human beings.

"Biodevastation" by illegal traffic of species is another direct threat to animals and, at the same time, an indirect threat to plants, insects and microorganisms. Direct threat means devastation of one species of animals provoking loss of one part of the trophic chain and, at the same, an increasing number of other animals, even plants and insects due to the loss of this specie (Bellard 2012). Illegal trafficking of certain species and even illegal traffic of parts or pieces of exemplars of a specie has increased. As pointed out by a recent report species in the Red List of CITES (International Convention of Trade of Endangered Species) are likely to disappear if such traffic would not detain (ONU 2016). This "biodevastation" is a further attack against biodiversity making more difficult to safe it against the climate change.

(III) Scientific Elements from a Pure Natural Science Viewpoint (Aspects of Biodiversity Conservation and Destruction)

One author expresses that "anthropogenic climate change can alter interspecific interactions and produce unexpected changes in species distributions, community structure, and diversity." (Harley 2011). The statement makes clear negative consequences to biodiversity due to Climate change of anthropogenic source (Bateman et al. 2013).

Although conventions on conservation, international agreements, have been enacted not much understanding of normative legally binding system has been developed. Clear examples are "effectiveness", "amount of treaties", "scope and participation" without including political willingness to define absence of effectiveness of these international treaties. The importance of international treaties is related to a first step in order to achieve conservation of natural resources.

(a) The General Effects on Biodiversity (IPCC)

In 2003 the Secretariat of the Convention on Biological Diversity addressed effects on biodiversity of climate change (Secretariat of the Convention on Biological Diversity 2002). As well, in 2002 The Framework Convention on Climate Changes has confronted this problem (Gitay et al. 2002). Expected and specific effects on biodiversity were, among others, poleward or upward movements of climatic range, extinction, replacement or change of existing ecosystems at the ecosystem or landscape scale, change of productivity of certain crops (upward or downward) (Secretariat of the Convention on Biological Diversity 2002). Further, the atmosphere is changing due to concentration of greenhouse gases provoking that temperature has increased in the global mean surface, earth and sea (Gitay et al. 2002) swelling the temperature on biological system during the 20th Century, changing "the timing of biological events (phenology), species distribution and streamflow, floods, droughts, water temperature and water quality and high latitude ecosystems in the Northern Hemisphere," and increasing "frequency and intensity of outbreaks of pests and diseases", affecting adversely coral reefs, ecosystems with diseases and toxicity, fish populations (Gitay et al. 2002). Such consequences has been described by some as affection of human well-being due to destruction or affection of "ecosystem services" (Watson et al. 2005).

It is possible to find as framework of this research a lack of legal rules in conserving biodiversity (due to negative consequences of climate change on biodiversity) as one of the reasons for this problem. As well, climate change on marine biodiversity should be addressed due to increasing problems in the subject (Galaz et al. 2012). On the other hand, researchers have developed few answers: Acclimation capacity of plants and animals as well as "topography and 'microclimatic buffering'" are elements altering conclusions of many models on destruction of biodiversity by climate change (Wilis and Bhagwat 2009). Topography seems to be the main problem not considered in earlier models (Wilis and Bhagwat 2009). Further, "habitat heterogeneity resulting from topographic diversity might be essential" for conservation of biota (Wilis and Bhagwat 2009). Even high impact of CO_2 in the atmosphere might create a positive outcome in the Amazonas, maintaining main features of the area as explained by Hoorn et al. (2010) because biomes or "remain the same" or might be "substitute by wetter or more productive biomass" but only if dry season is not extended than 4 months (Wilis and Bhagwat 2009). In this view, the level of extinction diminished (Wilis and Bhagwat 2009). Certainly, it is necessary to agree that complexity and uncertainty on the kind of extinction is currently present. However, it seems necessary not only to research but, more than this, to prevent extinction from more specific species and individuals without the capacity to move from one place to another.

Legally speaking some scholars has addressed the subject, most notably Morgera (2011, 2012) and Hodas (2005). What must be emphasized is that decisions in the Conference of the Parties of the Convention on Biological Diversity are not legally binding (ONU 1992a). Article 23 of the Convention of Biological Diversity has not established legally binding decisions of the Conference of the Parties. Certainly, the acceptance of protocols, amendments, annexes and even subsidiary bodies has been included in the competence of the Conference of the Parties. However, a direct amendment other orders included in decisions of the conference are far from obligatory. "Moratoriums of geoengineering" (Morgera 2011, 2012) are not internationally legally binding. Certainly, everyone might agree that rules in the Convention on Biological Diversity might be helpful for diminishing negative effects on biodiversity (Morgera 2011), however, they were "designed" to achieve the goals of the convention therefore their broadness in the area of conservation includes effects of contamination, illegal trade, etc. Further, all the legal rules in the Convention on Biological Diversity has established international rights and international obligations. Thinking contrary might derived in negative consequences for all treaties of the world. The Vienna Convention on the Law of Treaties (1969) developed international rights and international obligations as consequence of the entry into force of the Treaty (article 26) and to third parties (articles 35 and 36). Certainly, from a pure governance view, treaties might be considered in a different way, for example, as indications on how to behave. However, parties are obliged to comply their international obligations, they have to honoured them and use these international obligations as indications. They have to implement them in a narrow sense, apply them.

Therefore, it is possible to explain that negative effects on biodiversity from climate change depend on various factors related to features of Earth's surface. Further, it is necessary, for legal enactment of rules to consider legal quality of Decisions. They are just outcomes of the Conference of the Parties without legally binding rules.

(b) The Specific Effects on Biodiversity

It is possible to find examples of negative consequences to biodiversity. Some specific cases will be explained, briefly however, it has been described earlier start of breeding, earlier migration of birds and insects, change of timing of breeding provoking a mismatch with food species creating a surplus of certain species and possible disappearance of others due to lack of hunting and shortage of food (Gitay et al. 2002).

(b.1) Change on Forests and Biodiversity

Bateman et al. (2013) has pointed out the negative consequences in biodiversity by the effects of climate change when a change of the use of land should be made. In the UK National Ecosystem Assessment one of the main outcomes, methodologically speaking, was the consequence of on "optimal land uses" (Bateman et al. 2013). All "scenarios", six, using rule based approach, explain vast changes to land in England (Bateman et al. 2013). All scenarios will produce a change more or less negative and the "best" case scenario is current pattern of use of lands but without an increase in productivity unless the CO_2 increases (Bateman et al. 2013). However, this will provoke a destruction of biodiversity derived from the extreme agricultural use of the land without a precise improvement in the quality of life of people. This conclusion might be interesting for the UK's agricultural sector, North in the Hemisphere, but not for countries in the Southern part of the Northern Hemisphere or in the Northern part of the Northern Hemisphere.

Boreal forests are almost 30% of the global area of forests and losing them will create large gaps on ecosystem services (Gauthier 2015). On a regular base they are at high latitude (Northern or Southern Hemispheres). They are accustoming to strong winters with snow and low temperatures providing wood and shelter against wind and other services like conservation of animals, plants and microorganisms as well as the protection of water flows. They have large biodiversity between the species of trees even a "high population-level genetic diversity" (Gauthier 2015). Humans are provoking the creation of "extreme weather events" by very low profile events, even unperceived by human beings (Kerr 2007). Such events will change the current environment of boreal forests. It is a matter of time facing environmental change and disappearance of this forest.

On the other side of the world, rich biodiversity will disappear as consequence of effects of climate change, for example India, Brazil, South Africa (Mehdi 2010).

(IV) Proposals for a Solution of the Destruction of Biodiversity

Solutions in Saving Biodiversity

Some proposals for solutions in saving biodiversity acknowledged the uncertainty of the future of biodiversity (Hallegatte 2008) and might be explained shortly as first knowing what is there and their distribution (Jetz et al. 2007) through knowledge and later define which species to save and why. The "geography of life on earth" is extremely poor documented (Jetz et al. 2007). Therefore, it is needed further work on this matter for example global tracking of animals, plants and microorganisms. Today it is possible such tracking using international space stations following small animals as a project (Pennisi 2013). However, the question remains, we do not know every single species of biodiversity. Further, we are not able to have even a small amount of "usable knowledge" ("data analysis and forecast") and explanations (adapted from Kerr 2007) to take measures vis a vis conserving biodiversity. Such information might help to tackle specific ecosystems, animals, plants, insects and microorganisms or general ecosystems but with specific aims saving those that might be in specific and near danger like the one nearby shores in which the sea will be risen.

One proposal has been "passages" for biodiversity flows (CONAMA 2003). Considering that such passages would be establish from the shore to inland, biodiversity's shore will flow through those corridors escaping from the rising sea. Certainly, such idea was helpful in the beginning of the process of change of the climate. However, today is clear that degree and speed of change of species from one habitat to another one is low (Loarie 2009).

Another possibility is conserving species and even individuals of species ex situ, as established by the Convention on Biological Diversity. Unfortunately, it seems not enough considering the speed of climate change. Another possibility might be conservation in situ as established by the Convention on Biological Diversity. However, it is clear that the change of the climate would affect all populations in areas under threat of being changed by the effects of change of climate.

Legal or Normative solutions

(a) Harmonically Interpreting of Treaties

Treaties are in a legal system which might be considered an "International Rule of Law". Treaties do have legal rules establishing international obligations. These international obligations, in this case, obligation to conserve in situ or ex situ (ONU 1992a) would be complemented in an evolutionary interpretation (International Court of Justice 2010; Peña 2015) to conserve biological diversity to be affected or already affected by the effects of climate change in situ and ex situ.

(b) Amendment of International Treaties

International treaties do have amendments or might be complemented by new treaties derived from old one. Clear examples are the Paris Agreement and Nagoya Protocol. It is possible in this point in time to define an extremely short international agreement to move entire ecosystems from one place to another place in the same country or in a different one preserving rights of the State but promoting the conservation of the specie or species.

(c) A General Treaty on the Environment

A treaty on the environment encompassing all aspects of the environment establishing rights and obligations might include the conservation of areas by provoking and promoting change of species and individuals aiming conserving them, protecting them from current and future predators and controlling them from increasing in terms of population.

(d) Conservation Ex Situ and In Situ

This research is based on three assumptions, climate change provokes destruction of biological diversity, the change of place of biodiversity is a low race speed (extremely low race due to natural difficulties to move from a niche and achieve a different one), and human beings might be able to change biodiversity from the original place to a place in which conditions might be suitable to prevent extinction by conserving them. International legal rules are in place and it is just necessary to interpret them harmonically considering new problems for our biodiversity. Certainly, interpretation of the Convention on Biological Diversity and the Framework Convention on Climate change should be in good faith. The evolution of the problems related to climate change and biodiversity create the need to make a teleological approach and a preventive approach based on precaution and creating a positive legal framework for a conservation of biodiversity that need to move from their own natural territory to a new territory in order to be preserve should be established. Further work on the concept of conservation ex situ and in situ is needed.

A Brief Reflection on Lessons Learned

Certainly, it is not enough to define a lack of international policies and international and national legal rules related to destruction of biodiversity and the possibility of change of certain representatives of habitats and ecosystems to places in which they might survive such destruction. Such a lack exists and it is necessary to highlight it and to find legal solutions. However, the article has certain limitations; externally political willingness is needed to take policy, legal and practical measures to address the problem as exposed, internally, the article cannot deal with all scientific references (in a broad scope of the word "scientific") explaining the issue or discussing traditional solutions and possible new problems. However, such large amount of scientific knowledge has not come to a point in which political authorities would consider solutions to this problem. A first step was more based on counting the biodiversity than on saving biodiversity. Today counting and saving or saving for counting is a more reliable concept.

Limitations, from a legal standpoint, one of the expression of public policy, current solutions have not been conceived. However, it is a real problem to be treated in a scientific form and strong enough as the problem of the consequences of climate change almost 25 years ago. The discussion on the reality of climate change and the experiences thereof were at the core of the academic and social communities at that time. Today legal discussions should address more specific problems on the subject otherwise we will continue loosing the war against the effects of climate change on biodiversity (Cordonier-Seggier 2015). For example, legal rules permitting the movement of plant, animals, microorganisms, insects to safer areas. The movement by ex situ/in situ conservation to safer places. The definition of "safer places" by authorities and scientist. Monitoring of these places and the evolution of the interrelation of biodiversity in order to create habitats and ecosystems in safer places. Legal rights over land should be considered in order to apply old legal institutions or to create new legal institutions.

The current solution of gene banks and other sources of protection is not enough. These solutions focus on the main elements of plants, animals, insects and microorganisms the genes. However, they are not focus on the main problem of interrelations and even the idea of saving the life of these creatures. Certainly some of their interrelations have been described but not all of them.

From a pure public policy standpoint solutions based on documentation related to the aforementioned problem are a good first step. However, even the European Union has moved more on grassroots or local initiatives and not on national and international policies on the subject. Literature, on the other hand has not addressed this topic mainly to a lack of knowledge or on concentration on other real problems.

Conclusion

Lack of international legal rules preventing or managing effects of climate change on conservation of biological diversity is visible but no international initiative has been developed for negotiations on a treaty on the subject and the current international treaties on climate change or biodiversity were not firstly enacted to face the problem. Traditional solutions like counting or saving genes from biodiversity are positive but insufficient.

It is clear the current reality of the impact of climate change on biodiversity. It might be discussed destruction's degree, time and other important elements. However, measures under the framework of current international legal rules should be taken and re-interpretation of international treaties in a preventive, precautionary and consistent manner or development of new international legal rules following these ideas would be necessary to reinforce grass roots solutions and scientific warning. One measure, interpretation or enactment, might be first extraction of biodiversity (ex situ conservation) to finally preserve it in survival places under protection and monitoring (in situ conservation).

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Is Adaptation to Climate Change Threatening Forest Biodiversity? A Comparative and Interdisciplinary Study Case of Two French Forests

Timothée Fouqueray, Antoine Charpentier, Michel Trommetter and Nathalie Frascaria-Lacoste

Abstract France is highly covered by forests, upon which rely numerous jobs and natural habitats. Therefore, the country adopted a strategy of adaptation to climate change, leaning on a rich silviculture history to offer foresters various means to adapt (rotation shortening, species mixes, …). Still, different adaptations can be interesting in a given forest, depending on the trade-off between ecosystem services: timber production, biodiversity conservation, water quality preservation, … Hence, how do French foresters decide of the adaptation to implement? What are the impacts of their choices on biodiversity? The following explores how adaptation in the field occurs—a complementary approach of providing better understanding of the impacts of climate change on forest biodiversity. It analyses how biodiversity is included in field adaptations, and how this concords with guidelines of sustainable forestry. Results come from semi-structured interviews led in two French forests differing in anthropization, making use of ecology and geographic sciences. The analysis discriminates two non-exclusive positions on biodiversity: "utilitarists" adapting thanks to biodiversity and "conservationists" adapting for biodiversity. Utilitarists rely on species selection or introduction of allochtonous species to resist windstorms or biological attacks for instance, a potential threat for local populations. On the opposite, conservationists favor Darwinian adaptation over interventionist strategies. Conservationists would

T. Fouqueray (✉) · N. Frascaria-Lacoste
Ecologie, Systématique, Evolution, AgroParisTech, CNRS,
Université Paris-Sud, Université Paris-Saclay, 91400 Orsay, France
e-mail: timothee.fouqueray@agroparistech.fr

A. Charpentier
Master Bioterre, Université Paris, Panthéon Sorbonne, 75005 Paris, France

M. Trommetter
GAEL, INRA, CNRS, Grenoble INP, Université Grenoble Alpes, 38000 Grenoble, France

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for example prioritize spontaneous evolution, at the risk of tree species running short of time because of the speed of climate change. These results are integrated in a wider project including natural parks managers for decision-taking in forest management.

Introduction: Adaptation to Climate Change in Multifunctional Forests

French forests are Europe's fourth biggest forests (165,000 km^2), most of them being deciduous (MAAF 2017). Integrating biodiversity conservation in adaptation to climate change (ACC) policies is of highest importance, because of the ecological interest of forest environments and because of a French customary tradition of multifunctionality of public forests. More than just a state of mind, forest multifunctionality is legally embedded and states that public forests must simultaneously serve for various ecosystem services such as timber production, recreational activities *and* biodiversity conservation (Barthod 2015). This very peculiar context goes with a legacy of systemic public forest management and monitoring inherited from the sixteenth century. The necessity to integrate biodiversity conservation along with other forest ecosystem services is one of French characteristics that is of high interest because such constraints are commonly shared in a wide variety of situations.

Yet, even if the French government launched ACC policies and funded research programs, a knowledge gap persists concerning actual measures taken in the field. Better documentation of what really occurs in French forests is therefore needed to avoid putative maladaptation for forest biodiversity (Juhola et al. 2016). The rationale of this paper is therefore to explore what foresters actually do in the field to adapt, and more precisely how biodiversity is included in field adaptations. Maladaptation could indeed arise from utilitarian adaptations, when adapting *thanks* to biodiversity remains blind to Darwinian evolution (varietal selection ignoring climatic uncertainties, introduction of productive but invasive tree species, …). Additional issues might also stem from a conservationist strategy of adapting *for* biodiversity, with potential prioritization of spontaneous evolution regardless of the time lag between tree Darwinian evolution and the speed of climate change (Corlett and Westcott 2013). Getting insights on how foresters behave when confronted to climate changes is key to develop accurate incentives in public policies. This paper could be of particular interest for informing both the 2018 renewal of France 4-years Mitigation Strategy and National Plan for Adaptation to Climate Change.

In the end, how do French foresters decide of the adaptation to implement? What are the impacts of their choices on biodiversity? In order to examine these issues, results from a field study depict how foresters consider biodiversity in their adaptations to climate change. We analyzed the collected mentions of ACC in the light of a few management principles for a sustainable forestry: avoidance of natural habitats loss, maintenance of ecological connectivity, maintenance of forest heterogeneity (diversity of species, ages and successional stages), focus of management onto the landscape scale, avoidance of forest-use intensification (Noss 2001; Lindenmayer et al. 2006; Brang et al. 2014).

Methodology: Framing an Interdisciplinary Study Case

To evaluate on-the-ground adaptations, we carried out individual semi-structured and open-ended interviews in France during June and July 2017. Interviewees were private owners, officials from municipalities and central agencies, and forest managers.

Ecologists usually base their environmental analyses on the production and validation of logical knowledge (Moon and Blackman 2014). Yet, ecological consequences of ACC practices are due to human reasoning and motivations departing from objective mechanisms. Hence, a constructivist method fits with the objective of exploring how interviewees relate (or not) biodiversity conservation with ACC in forest management (Kaufmann 2004). Each interview consisted of (i) a general description of the interviewee's silvicultural practices, (ii) a description of the temporal evolution of these practices and (iii) the interviewee's opinion about brakes and levers to reach desired silvicultural practices. If not spontaneously mentioned, we also asked what were their reactions following last decade's natural disturbances, for instance Lothar-Martin windstorms in 1999 or 2003 droughts (Ministère de la Transition écologique et solidaire 2017).

Every interview was recorded, fully transcribed and qualitatively analyzed. Audio tracks and written transcriptions were analyzed using Sonal, an encoder-software conducting audio-textual synchronization. Sonal allows for thematic and statistic discourse studies, such as topic occurrences and/or co-occurrences (e.g. "logging practices" and/or "forest uses") (Nicolas 2013). To be considered as an ACC, an interview sample should mention the expression of a change in forest management practices, either explicitly linked with climate change (ex: "first thing, forest stand management in the context of climate change"), or implicitly linked with at least one of climate change consequences (ex: mitigation policies and demand for non-fossil energy sources "we used to produce around 35,000 tons of fuelwood"). Once an interview sample was referenced as mentioning an ACC, it was characterized depending on adaptation category, interventionism level, motive, temporality, spatial scale of application, adaptation of what, adaptation to what. To avoid arbitrary classifications, characterizations were cross-checked by another author after being carried out by one author.

Adaptation category. Mentions of ACC were classified under the categories "Forest-use market diversification", "Insurances", "Land-use change", "Natural selection" (e.g. forest stands with spontaneous evolution),"Research and development", "Silvicultural changes - forest density", "Silvicultural changes - pest control", "Silvicultural changes - physical and chemical environment", "Silvicultural changes - quality management", "Silvicultural changes - rotation length", "Silvicultural changes - technical itinerary" (e.g. Conversion of a regular woodland into an uneven-aged stand), "Silvicultural changes - tree species", "Social innovation" (modifications of social interactions, e.g. creation of forest tales about climate change), "Timber market diversification" (e.g. selling timber products as fuelwood, lumber, wood for paper fibres, …).

Interventionism. Interventionism qualified whether adaptations could have occurred without human intervention. When applicable, assessment of whether the ACC 'would exist without human intervention', 'reversibility' and 'coercition of ecological dynamics" were based on interviews analyses and cited literature. An ACC was considered 'existing without human intervention' when it occurs in the wild (e.g. species mixes), 'reversible' when the time needed to return to pre-adaptation conditions is lower or as long as the implementation time of the adaptation (e.g. thinning is reversible, because it occurs every decade, long enough for forests to densify again). 'Coercition of ecological dynamics' qualified an ACC as going counter-current of the ecological dynamics ('Control and Command') or as accompanying ecological dynamics ('Monitor and Adapt'). For instance, if a local tree population declines because of rarefying rainfalls or increasing droughts, its maintenance through artificial plantations would correspond to 'Control and Command'. In this case, a 'Monitor and Adapt' envision of ecological dynamics could be funding research and development for adapting timber transformation machines to the tree species replacing the declining one.

Motive. Purposes of adaptations were assessed using a 'adapting for or by biodiversity' and a 'adapting for forests or for social-economic systems' criteria. Assessments stemmed from interviewees' expressed opinions.

Temporality. Reactive adaptations are "adjustments in ecological, social, or economic systems in response to observed or expected changes in climatic stimuli and their effects" (Adger et al. 2005). Hence, an ACC was counted as reactive when an interviewee implemented it to avoid detrimental impacts of a climatic risk already experienced (windstorm, fire, …). Proactive adaptations are measures taken to lessen the perceived negative impacts of future events (Engle 2011). An ACC was therefore counted as anticipative when the interviewee mentioned it as an a priori preparation of predicted climate changes. When the action of ACC was first a by-product of another action, it was considered as "Side effect of other silvicultural changes" (e.g. resulting from economic strategies, some shortened rotations also have interest for ACC).

Spatial scale of application. The scale of the ACC was always clearly apparent or explicit in the interviews. Spatial scales described the spatial extent of the ACC: the individual (ex: inclusion of silvicultural changes in popular culture), the forest stand, the municipality, the whole forest (massif) or the whole country (ex: observatory network of the effects of climate change on trees).

Adaptation of what. Discourse analysis gathered elements highlighting what ecosystem services were preferentially targeted by interviewees' ACC.

Adaptation to what. Discourse analysis gathered elements highlighting what were the risks against which interviewees mentioned ACC. For instance, shortening rotation lengths was sometimes displayed as an ACC to drought, sometimes to windstorms.

As any methodology, ours has its own limitations. In several interviews, it was not possible to cross-check the interviewees' statement with field visits (interviews were nevertheless included in the study). Another limitation pertains to sampling biases: because interviewees are by definition foresters within reach of researchers, they are also involved in professional networks prone to release informations about ACC. This was taken into account in the analyses, but as this bias applies to every interviewees, it was not considered as questioning our results.

The selection of study areas was guided by social-ecological considerations so to retain two very contrasted forests characterizing polar opposites of French forest management (see Table 1). The first study area—the man-created forest of the "Landes de Gascogne" (hereafter refered to as "Landes")—lies in southwestern France and is grounded on a young and very interventionist history. The draining of former marshlands two centuries ago led to a mechanized and monocultural forestry. Soils are plowed to plant selected seedlings (*Pinus pinaster*) that are usually clearcut between their thirtieth and fortieth year. On the opposite, the second study area, known as the "Vosges du Nord" ("Vosges"), displays a silvicultural history that dates back over 400 years (Jéhin 2005): an important proportion of forests are composed of uneven-aged and mixed stands. These areas were also chosen on the basis of local natural parks managers showing interest in ACC studies linked with biodiversity issues. It must be kept in mind that our study areas are not representative of the whole French silvicultural technics range. Hence, our results must not be taken as applicable for the whole country: they reflect two distinct and strong opposites of how foresters deal with ecological processes in their silvicultures.

In that respect, forests can be studied as social-ecological systems (SES), for they couple Darwinian adaptation with socio-economic adaptations arising in interconnected demographic, cultural and economic contexts (Anderies et al. 2006). An interdisciplinary combination of geography and ecological sciences is therefore relevant to address the inclusion of biodiversity in foresters' ACC measures.

Results

97 mentions of ACC were compiled from a total of 27 interviews (13 in the Landes, 14 in the Vosges). Only one forester did not explicitly mention any ACC, but he insisted on his silvicultural practices being flexible to environmental and external changes. Interviews were usually 1–2 h long, but could last up to 5 h.

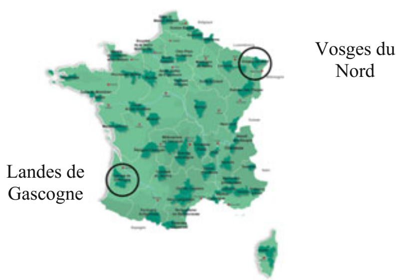
Adaptation category. Changing tree species (mixes, replacement, …), acting on the physical and chemical environment (by subsoiling, fertilization, …) and diversifying timber sales are the three most widespread mentions of ACC (Table 2). On the contrary, diversifying forest economic uses (tourism), innovating socially (development of forest tales related to climate changes) are the two least mentioned ACC (Table 2).

Interventionism. Interviewees predominantly mention interventionist ACC. 49 out of 97 ACC would not occur without human interventions (e.g. shortened cutting age to avoid climate risks artificially modifies the age pyramid of forest stands) (Table 2). 8 out of 14 categories of ACC are not reversible. In terms of coercition of ecological dynamics, 63 ACC envision biodiversity in a 'Control and Command' way, going counter-current of the ecological dynamics occurring (e.g. artificially maintaining a declining tree population by plantations).

Motive. Where applicable, a vast majority of the ACC consider biodiversity as a tool to adapt and not as an adaptation motive (57 ACC among the 97 are 'by diversity'), without exclusivity of the two approaches (11 ACC considered biodiversity both as a tool and an objective) (Table 2). 5 out 14 ACC categories aim at modifying forest ecosystems (change in the relative abundance of tree species or in the age and height structures of forest stands, etc.) and not at modifying social-economic systems (incentive to buy insurances against storms, cultural acceptance of free evolution, etc.) (Table 2).

Temporality. An ACC could be counted both as reactive and anticipative, because a given ACC can arise after a climatic hazard and also in prevention of upcoming climatic hazards. ACC are slightly more mentioned because of experienced climatic hazards than because of forecasted climate changes. However, among the climatic

Table 1 Comparative description of the two study areas

	Landes de Gascogne	Vosges du Nord
Forest composition (proportion of the park)	*Pinus pinaster* (80%), *Quercus robur* (12%)	*Fagus sylvatica*, *Pinus sylvestris*, *Quercus* sp. (together 60%)
Private ownership	95%	15%
Number of interviewees	14	13
Vulnerability to climate change	Droughts, fires, windstorms, parasite risks	Droughts, windstorms
Natural regional park	Yes	Yes
Location map		

Source of the map: www. http://www.parcs-naturels-regionaux.fr/

Table 2 Classification of the 97 adaptations to climate change collected from French foresters, with their interventionism characteristics

Adaptation category	Number of occur-rences	Examples	Adaptation for or by biodiversity?				Adaptation of forests or of social-economic (human) systems?	Would the adaptation exist without human intervention?				Reversibility	Coercition of ecological dynamics		
			By	*For*	*For and by*	*NA*		*Yes*	*No*	*Maybe but slower*	*NA*		*Control and com-mand*	*Monitor and adapt*	*NA*
Insurances against climatic hazards	2	Insurances against windstorms	–	–	–	2	Humans	–	–	–	2	Yes	0	2	0
Land-use change	8	Switch to photovoltaic plants or organic agriculture by land clearing	–	–	–	8	Forests	–	8	0	–	No	8	0	0
Timber market diversification	12	Sales diversification towards fuelwood, introduction of contractual sales of timber	9	3	0	–	Forests	–	–	–	10	Yes	9	3	0
Forest-use market diversification	1	Market diversification towards non-timber forest products (mushrooms) and recreational activities	1	0	0	–	Humans	1	0	0	–	Yes	1	0	0
Research and development	4	Establishment of regional observatories of climate change	1	3	0	–	Humans		3	1	3	Yes	1	3	0

(continued)

Table 2 (continued)

Adaptation category	Number of occurrences	Examples	Adaptation for or by biodiversity?				Adaptation of forests or of social-economic (human) systems?	Would the adaptation exist without human intervention?				Reversibility	Coercition of ecological dynamics		
			By	*For*	*For and by*	*NA*		*Yes*	*No*	*Maybe but slower*	*NA*		*Control and command*	*Monitor and adapt*	*NA*
Natural selection	9	Acceptance of spontaneous evolution in forest stands	2	3	4	–	Humans	9	0	0	–	Yes	0	9	0
Social innovation	1	Storytelling of forest and climate tales for children	–	–	–	1	Humans	0	1	0	–	Yes	0	1	0
Silvicultural changes—forest density	7	Reduced forest density	7	0	0	–	Forests	1	6	0	–	No	7	0	0
Silvicultural changes—physical and chemical environment	12	Subsoiling, soil tillage, fertilisation	2	0	1	9	Forests	1	11	0	–	No	10	2	0
Silvicultural changes—tree species	29	Species mixes, varietal selection, assisted migration, species replacement	26	0	3	–	Forests	13	12	4	–	No	20	7	2
Silvicultural changes—technical itinerary	3	Close-to-nature forestry	1	0	2	–	Forests	3	0	0	–	Yes	0	3	0

(continued)

Table 2 (continued)

Adaptation category	Number of occurrences	Examples	Adaptation for or by biodiversity?				Adaptation of forests or of social-economic (human) systems?	Would the adaptation exist without human intervention?				Reversibility	Coercition of ecological dynamics		
			By	*For*	*For and by*	*NA*		*Yes*	*No*	*Maybe but slower*	*NA*		*Control and command*	*Monitor and adapt*	*NA*
Silvicultural changes—pest control	2	Biocontrol using *B. thuringiensis*	1	0	1	–	Forests	1	1	0	–	No	1	1	0
Silvicultural changes—quality management	2	Increased stand thinning	2	0	0	–	Forests	0	2	0	1	No	1	1	0
Silvicultural changes—rotation length	5	Shortened rotations	5	0	0	–	Forests	0	5	0	–	Yes	3	2	0
TOTAL	97		57	9	11	20		29	49	5	16		63	32	2

Figures correspond to the number of occurrences of an adaptation category in the interviews. For instance, "insurances against climatic hazards" count for 2 adaptations out of the 97 identified in the interviews; in these cases, adaptations touch upon social-economic systems, they are reversible and in a 'Monitor and Adapt' vision of ACC

Table 3 Adaptation to what? Reasons of silvicultural changes mentioned by interviewees, classified by reaction or anticipation

Silvicultural changes driven by…	In reaction to a past climatic event	In anticipation to forecoming climatic events	Change first mentioned as an adaptive side effect of other silvicultural evolution unrelated to climatic hazards	Reaction or anticipation not specified	Total
Demand for renewable and non-fossil energy	15	–	–	–	15
Frosts	3	1	–	–	4
Hailstorms	–	1	–	–	1
Fires	4	3	–	–	7
Windstorms	24	6	2	–	32
Droughts	6	22	4	2	34
Parasite attacks	4	8	–	–	12
NA	–	10	–	2	12
Changes in rainfall patterns	–	4	2	1	7
Wildlife browsing	–	1	–	–	1
Demand for carbone capture and storage	–	–	1	–	1
Mix of at least two of the climate changes	3	6	–	–	9
Total	59	62	9	5	–

Figures correspond to the number of occurrences of an adaptation category in the interviews. (Because a silvicultural change can arise from different reasons, some ACC were counted twice, hence totals are superior to 97.) For instance, 12 adaptations were mentioned as dealing with parasite attacks, among which 4 followed a parasite attack and 8 anticipate parasite attacks

changes most feared in anticipation, drought already stroke the Landes and Vosges several times last decades (Table 3). Thus, ACC that were mentioned either in reaction or in anticipation to climatic risks essentially arise from past and experienced climatic hazards (Table 3).

Table 4 Adaptation of what ecosystem services, on what spatial scales? Forest services mentioned as the interviewees' focus for ACC, classified by spatial scale

Forest use or ecosystem service to be adapted	Total number of occurrences	Spatial scale				
		Individual	Forest stand	Municipality	Forest massif	Country
Timber production	63	–	45	–	16	2
Not applicable (NA)/Undefined by interviewee	14	–	8	–	5	1
Land use	8	–	4	4	–	–
Timber production *and* biodiversity	4	–	2	–	2	–
Timber production, biodiversity *and* esthaetic landscape	3	–	2	–	1	–
Recreational activities	1	–	1	–	–	–
Biodiversity conservation	1	–	–	–	1	–
Soil retention to prevent erosion	1	–	–	1	–	–
Cultural heritage (forest history)	1	1	–	–	–	–
Human health	1	–	–	–	1	–
Total	97	1	62	5	26	3

Figures correspond to the number of occurrences of an adaptation category in the interviews. Ex: among the 4 ACC aiming at adapting timber production *and* biodiversity, 2 were designed at the forest stand level and 2 at the forest massif scale

Spatial scale of application. Adaptations largely apply at the forest stand scale (62 mentions out of 97) and at the forest scale (23 mentions). Noticeably, only one ACC concerned the individual scale: cultural heritage, in other words, the development of forest tales linked with climatic hazards (windstorms) (Table 4).

Adaptation of what. ACC first aim at adapting timber production (63 mentions out of the 97 mentioned ACC). There is only one instance of ACC of biodiversity for itself, while the other ACC aiming at adapting biodiversity are always related either to the adaptation of timber production or of aesthetic landscapes (7 mentions) (Table 4).

Adaptation to what. Top-mentioned ACC are mostly in responding to punctual and already experienced climatic risks: droughts (34 citations), windstorms (32 citations), demand for renewable and non-fossil energy (15 citations), parasitic attacks (12 citations) (Table 3).

Discussion

Biodiversity Conservation as an Adaptation by-Product of Utilitarian Timber Production

Contrasting with the often reported lack of ACC implementation (Campbell et al. 2008), almost all interviewees mentioned ongoing or operational adaptation measures—97 in total (Table 2). This can be attributable to the long-term planning of forest management and to the strong forest cultures of the Landes and the Vosges. Following Carpenter et al. (2001), two main questions can shape the study of how biodiversity issues are integrated among these 97 ACC. *To what* climatic risks are forest adapted? *What* are the forest goods and services targeted?

The first lesson from the field about *to what* foresters adapt is common: ACC were mostly in reaction to droughts and windstorms, two climatic hazards that occurred in both study areas (Table 3). For instance, Lothar-Martin windstorms in 1999 devastated more than 30% of the Landes stands and also hit the Vosges, as put simply by a forestry advisor: “When the wind is strong here, many people can’t sleep anymore…”. Reactive adaptations are rooted in the enhanced perception of risks already experienced, a cognitive bias found in other environments (Rey-Valette et al. 2012). Paradoxically, the third most mentioned ACC is not related to climate hazards but to an indirect consequence of mitigation policies. The mitigation-driven demand for renewable and non-fossil energy sources leads to increased fuelwood supply through slash and stump removal, seen as a business opportunity for wood producers.

Interviewees also detailed *what* forest services they try to adapt, and biodiversity conservation was clearly less cited as an adaptation target than timber production (by far the top-ranked one, Table 4). Moreover, biodiversity conservation was nearly systematically mentioned along with forest scenery or timber production (Table 4). This is not surprising, as timber production is the major source of income and concentrates adaptation efforts. To quote a forest manager, “Today, forest owners only earn money from timber sales, around 90% of their incomes, with lease of hunting being the other 10%. The rest of it [biodiversity conservation and carbon sequestration] is a gift to the society, and we even pay property taxes for that!”. Careful application of payment for ecosystem services could be an interesting way out of the predominance of timber production in ACC, with a collective share of biodiversity conservation costs (Farley and Costanza 2010).

This focus on timber production might explain why forest stand is the spatial scale referred to as the most efficient to achieve ACC (64% of all ACC mentions). Timber production is indeed designed and managed at the forest stand level. This raises the issue of spatial integration of biodiversity dynamics, which do not stop at the forest stands limits. The ACC emphasis on forest stands could be a brake for managing ecological connectivity, one of the putative safeguards for biodiversity conservation being the key role played by natural parks authorities. Supporting this vision, it is almost only forest officials with responsibilities regarding biodiversity conservation who cited the whole forest as their ACC spatial scale—the second most cited spatial scale (Table 4). As an example, Vosges park managers underlined the necessity to plan ACC at the forest scale because they must ensure ecological corridors. To rebalance the impacts of shortened rotations, they established a no-management network composed of old-growth patches. Authorities of deconcentrated services of the Ministry of Environment also expressed their full consideration of long-term changes (e.g. phenological or temperature shifts), even if ACC in anticipation were less implemented than reactive ACC. Concerns persist because authorities (whether from natural parks or from State services) must comply to national public policies that did not prove very pioneering regarding biodiversity conservation. For instance, it is only in 2017 that the national plan for adaptation to climate change incorporated recommendations for protected natural areas and biodiversity (Observatoire National des Effets du Réchauffement Climatique 2017).

Biodiversity Conservation Overwhelmed by an Interventionist Approach of Adaptation to Climate Change

Interviewed foresters mostly considered biodiversity as a tool to adapt and not an adaptation goal in itself, as outlined in Table 2. However, a utilitarian approach of biodiversity does not necessarily imply an interventionist conception of ACC. Successful silvicultural attempts exist that balance long-term utilitarian cost-minimizing timber production with environmental imperatives (Brang et al. 2014). In France, the ProSilva organization promotes a close-to-nature forestry with mixed forests, heterogeneous structures, natural regeneration when possible and avoidance of clear cuts (de Turckheim and Bruciamacchie 2005; ProSilva 2017). Interviewed in the Vosges, a prominent member of ProSilva summarized his vision of biodiversity as an ACC tool: “Stability of production is important. So a diversified system is more stable, more perennial than a house of cards. Any grain of sand and everything collapses, then you’re lost.”

Still, most of the 97 collected ACC were interventionist, for instance excluding the social-economic system as the adaptation target to be modified in order to ensure ACC (Table 2). In other words, human intervention condition most of the reported ACC, such as planting trees according to windstorms tracks to decrease their wind surface areas. Human intervention is not always by essence detrimental to biodiversity, when it comes to conservation efforts—even if they are most often designed to offset anthropogenic forcing. For some forest species, concerns exist about their ability to adapt fast enough (through Darwinian evolution, dispersion, range expansion or phenotypic plasticity) (Campbell et al. 2008). More specifically, trees have long generation time and some species have low ability to disperse (Corlett and Westcott 2013); issues of time lag between climatic changes and biological responses could make it relevant to plan human-based adaptation of such organisms (Millar et al. 2007). However, virtually none of the interviewees spontaneously came to that question.

Most of the mentioned ACC mentioned are irreversible and therefore very sensitive issues when dealing with species mixes and provenances. For instance, the intentional translocation of tree populations to account for climatic risks (assisted migration) can introduce unwanted genotypes in target environments (Millar et al. 2007; Lefèvre et al. 2014). Great care must be taken not to forget key ecological mechanisms, such as translocation of tree populations without considering their extended phenotype—their association with soil fungi or arthropods communities on source sites (Frascaria-Lacoste and Fernández-Manjarrés 2012). Most of species-based ACC mentioned were cautious in implementation, as for instance the migration of an oak population from southern France into the Vosges to address temperature shifts. Still, even if this pilot experiment did not foster non-native species introduction, careful monitoring is required to evaluate whether introduced trees outperform local populations or if they contribute to genetic mixing. French ACC public policies could be a way to implement precautionary measures with respect to sustainable forestry principles (Sansilvestri et al. 2015).

Interventionism is also significantly rooted in the coercition of ecological dynamics, as suggested by the prevalence of 'Control and command' ACC (around 65% of ACC). For these ACC, adaptation focuses on a single variable of the environment without integrating potential side-effects, often supported by a technological framing of the response to a climatic hazard. An archetypal example is provided by some Landes forest owners, who aim at extending soil root exploration on their forest stands. Before planting, some of them used 250 horse-power subsoilers to break the hardest horizon of the soil. However, they sometimes reported maladaptation to droughts, for subsoiling increased water draining and lowered water soil retention. Moreover, their stand were less resilient to windstorms, because maritime pines would break in two instead of falling untouched on the floor as a consequence of their deeper root anchorage. This 'Control and command' ACC was only focusing on adaptation to droughts and hindered access to forest stands and harvest of damaged trees, disregarding forest complexity.

In the end, the interviews allow to examine the impacts of ACC choices on biodiversity through the prism of the sustainable forest principles:

- *Avoidance of natural habitat loss* could suffer from shortened rotations, as fewer old trees hosting cavities would stay in forests after logging (Fan et al. 2004; Lindenmayer et al. 2006). In the Vosges, attention has been focused on the loss of cavity trees, and a compensatory network of old-growth trees has been implemented for thirty years.
- *Maintenance of ecological connectivity* and *focus on the landscape scale* is of greater concern, as the most quoted spatial scale was the forest stand.
- *Maintenance of forest heterogeneity* (diversity of species, ages and successional stages) first depends on owners' silvicultural practices. In public forests, the multifunctionality injunction imposes to take biodiversity into account, but on-the-ground implementation is at the discretion of local managers. In the Landes forests, owners are mainly individuals who pay a tax dedicated to fire prevention, a brake for fire-based heterogeneity of forests but a prerequisite for timber production

(Doustin 1975). Forestry goals and local contexts therefore greatly condition the forest heterogeneity management principle, with consideration through ongoing research about tree diversity and herbivory by forest insects (Jactel and Brockerhoff 2007).

– *Avoidance of forest-use intensification* might be the biggest focus point when it comes to adaptation to the indirect effects of climate change. Economic adaptation to the rise in fuelwood demand, indirectly due to mitigation policies, could lead to extended harvest of slash and stump, threatening long-term soil equilibrium (Jandl et al. 2007; Walmsley and Godbold 2010). Inertia of private owners could nevertheless balance intensification of forest-use, as shown by several interviews: numerous forest owners cannot afford investments in forest roads or have too small forest holdings to derive benefits from fuelwood sales.

Conclusions

In order to assess potential long-term adverse effects of ACC on biodiversity conservation, we interviewed foresters, forest authorities and forest owners. Two forest cases contrasting in anthropization were selected: the “Landes de Gascogne” and the “Vosges du Nord”, both study areas complying with France’s forest specificities: vast, multifunctional, and managed (at least public forests). Analyses of the collected mentions of ACC were conducted in the light of sustainable forestry principles: avoidance of natural habitats loss, maintenance of ecological connectivity, maintenance of forest heterogeneity, focus onto the landscape scale, avoidance of forest-use intensification (Noss 2001; Lindenmayer et al. 2006; Brang et al. 2014).

Much of ACC mentioned were utilitarian—considering biodiversity as a tool to adapt and not as a conservation goal. Much of them were also interventionist, designed to adapt forest environments to timber production, most often without questioning the adaptation of human social-economic systems. Based on the interviews, integrating biodiversity conservation within this interventionist context seems highly relevant, since timber production should probably persist as one of forest most used ecosystemic services, a consideration found across other research projects (O’Hara and Ramage 2013). Still, numerous difficulties persist to evaluate the impacts on biodiversity of ACC of forestry practices. Are interventionist ACC required for biodiversity conservation, or can forest environments adapt to climate change without human interventions? In a few cases, such as shortened rotations or subsoiling, effects on biodiversity of interventionist ACC are quite straightforward to measure. But interventionism is not always so unequivocal, due to numerous ecological and climatic uncertainties (Campbell et al. 2008). An example is assisted migration, where uncertainties are high about the tree real velocity, dispersal, acclimation to phenological shifts or about gene flow from supposed adapted populations, not to mention the variety of ecological processes harsh to evaluate (Frascaria-Lacoste and Fernández-Manjarrés 2012; Corlett and Westcott 2013).

Favoring intervention or spontaneous evolution is of no little importance, but uncertainty renders it difficult to follow accurate guidelines (Hallegatte 2009). When considering the implementation of an ACC, we first recommend end-users to base their practical decision-making on sustainable forestry principles. When applicable, we also suggest to include uncertainty in their everyday silvicultural practices by systematically preferring the one option with positive outcomes over a wide range of futures, in order to avoid "putting all eggs into one basket" (Dessai et al. 2009; O'Hara and Ramage 2013).

These silvicultural practices impacting forest environments are based on social and economic decision-making. Thus, interdisciplinary research is critical to long-term successful biodiversity conservation. Understanding adaptation processes is one thing, but basing nature parks management on recent knowledge is another. From a conservationist point of view, ACC *for* biodiversity conservation is a challenge that requires maintained and enhanced exchanges between researchers from different fields and nature parks managers (Stein et al. 2013). Learning from literature study cases and formal and informal professional meetings stays indispensable to encourage capacity-building and adoption of the 'Monitor and adapt' management paradigm. In this logic, reversibility of ACC and ecological threshold uncertainties—genetic bottlenecks, effects of thinning or slash removal on ecosystem functioning, …—are to be monitored. 'Monitor and adapt' could also participate in integrating laisser-faire measures as a pro-active choice within the ACC range.

Considering that forest officials are those accounting the most for biodiversity, it would also be legitimate to question whether their interactions with forest owners or forest experts leads to better integration of these forest sustainability principles. Methodological constraints do not allow us to go beyond the one-to-one interviews, but another research project is in progress. Based on companion modelling and serious games (Bousquet and Le Page 2004; Abbrami et al. 2015), it aims at analyzing the importance of communication between forest stakeholders for incorporating biodiversity conservation in the players' ACC strategies.

Explicitation of how foresters first consider biodiversity as a utilitarian tool to maintain productive forests could be our main result for biodiversity conservation. This could be a significant asset for biodiversity conservation in non-protected forests. Indeed, clarifying the value of biodiversity for ACC is a first stage to rise awareness about conservation importance—so long as the utilitarian perception of biodiversity is not the only one. In this light, the emergence of public policies relying on ecosystem-based adaptation and on nature-based solutions is a step in this direction (Balian et al. 2014; Eggermont et al. 2015). Aiming at turning adaptation *with* nature into something as efficient as adaptation *against* nature, this promising concept could become in the coming years a useful communication tool reconciling biodiversity conservation with other ecosystemic services in multifunctional environments. In 2018, renewal in France of both the national plan for adaptation to climate change and the national mitigation strategy will be chances to assess the inclusion of nature-based solutions in public policies for biodiversity conservation.

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Hypotheses from Recent Assessments of Climate Impacts to Biodiversity and Ecosystems in the United States

Shawn L. Carter, Abigail J. Lynch, Bonnie J. E. Myers, Madeleine A. Rubenstein and Laura M. Thompson

Abstract Climate change poses multiple threats to biodiversity, and has already caused demonstrable impacts. We summarize key results from a recent national assessment of observed climate change impacts to terrestrial, marine, and freshwater ecosystems in the United States, and place results in the context of commonly articulated hypotheses about ecosystem response to climate change for global implications. Specific impacts we consider include: range shifts; phenological shifts; phenotypic changes; primary production changes; biological invasions; and novel communities. Significant effort has been made recently to incorporate adaptation measures into land and water management at both national and international scales, but the scale of impacts and associated uncertainties pose challenges to existing management institutions. Using commonly articulated hypotheses about climate change, biodiversity, and ecosystem response can provide context for informed decisions at multiple scales and can help to provide a clearer understanding of the ecological and mechanistic linkages between climate change and biodiversity.

S. L. Carter · A. J. Lynch · B. J. E. Myers · M. A. Rubenstein (✉) · L. M. Thompson
National Climate Adaptation Science Center, US Geological Survey,
12201 Sunrise Valley Drive, Reston, VA 20192, USA
e-mail: mrubenstein@usgs.gov

S. L. Carter
e-mail: scarter@usgs.gov

A. J. Lynch
e-mail: ajlynch@usgs.gov

B. J. E. Myers
e-mail: bjmyers@usgs.gov

L. M. Thompson
e-mail: lthompson@usgs.gov

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Introduction

Contemporary anthropogenic climate change is increasingly impacting biodiversity and associated ecosystem services (IPCC 2013). Terrestrial systems are experiencing rising air temperatures, increasing incidences of large forest fires, reduced snow pack and earlier spring melt, and an increasing number of extreme precipitation events (Wuebbles et al. 2017); freshwater systems are experiencing changing temperatures, flow regimes, and precipitation patterns (Rahel and Olden 2008; Jimenez Cisneros et al. 2014); and marine systems are additionally affected by sea level rise, acidification, and altered ocean circulation (Brierley and Kingsford 2009). Furthermore, these impacts are expected to increase in frequency or intensity into the future as warming accelerates (Urban 2015).

Such changes in climate have significant impacts on biodiversity, including shifts in the relative distribution or abundance of organisms across habitats (range shifts); changes in the timing of important life history events (phenological shifts); trait changes that can better cope with new environmental conditions (phenotypic changes); changes in the production of biomass by photosynthetic organisms (primary production changes); increases in the presence or abundance of alien invasive organisms across regions (biological invasions); and changes in species interactions (novel communities). Understanding the rate and magnitude of these changes and consequences is critical to informing future natural resource management decisions in the face of climate change. Furthermore, understanding these impacts specifically in the context of scientific hypotheses can help to clarify important underlying processes and mechanisms, and serve as a framework to inform future research, modeling, and assessment efforts. In this paper, we draw upon recent climate assessments in the United States for the purpose of illustrating impacts which are already being observed and quantified. In addition, we articulate a series of hypotheses about biodiversity response to climate change and present an argument for how such a framework can help to inform future research and decision making.

Recent assessment activities internationally and in the United States have provided insight into the implications of climate impacts to biodiversity and have highlighted potential management responses. Internationally, the United Nations' (UN) 2030 Agenda for Sustainable Development and associated Sustainable Development Goals (SDGs), as well as the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD), recognize that improved management and conservation of biodiversity is central to achieving international goals for human and environmental well-being (Sachs et al. 2009; Secades et al. 2014; Romanelli et al. 2015). In the United States, the National Climate Assessment (NCA) is a quadrennial report that synthesizes the state of scientific knowledge about the status and impacts of anthropogenic climate change, and analyzes impacts to both human and natural systems. A recurring chapter devoted to Ecosystems, Ecosystem Services, and Biodiversity

(Groffman et al. 2014) specifically reviews observed climate impacts on biodiversity and resulting changes in ecosystem services on national and sub-national scales. The 4th NCA, scheduled for release in 2018, brought together experts from 13 Federal agencies, academia, and non-governmental organizations to synthesize literature on observed climate change impacts in the United States. Such assessments can help decision makers better understand risks and manage for the most significant impacts of climate change by highlighting how valuable ecosystem services may be affected (Alcamo 2005; Jones et al. 2014).

Here, we provide a hypothesis-driven synthesis of climate change impacts to biodiversity in the United States, structured around the type of impact (range shifts; phenological shifts; invasive species; changes in primary production; novel ecosystems; and phenotypic changes) and ecosystem type (terrestrial, freshwater, and marine) (Table 1) and review implications for potential adaptive management responses (Table 2). While an exhaustive assessment of evidence for and against each hypothesis is beyond the scope of this piece, we provide an overview of observed impacts structured around each type of impact and a framework for a hypothesis-driven impact assessment (Table 1). This effort will assist with anticipating potential impacts of climate change in the U.S., clarify how those impacts vary within and across ecosystem types, and help to identify science-informed management options that minimize harm to biodiversity.

Synthesis of Impacts

Range Shifts

Species are expected to shift their geographic distribution in order to stay within their climate niche (Parmesan and Yohe 2003); higher elevations or latitudes for terrestrial and freshwater systems and deeper depths for marine systems (Chen et al. 2011, Urban 2015). Species' capacity for range shifts is limited by their inherent adaptive capacity, as well as by other drivers of spatial distributions (e.g., predators and competitors, land use changes, availability of migration corridors). In instances where range shifts cannot accommodate the pace of climate impacts, local extinctions are expected (Wiens 2016). Range shifts have numerous implications for socially important aspects of biodiversity on an international scale, including fisheries stocks that no longer align with existing management boundaries (Pinsky and Fogarty 2012; Barange et al. 2014) and expanding ranges of vector-borne diseases, such as Lyme disease, malaria, and avian flu (Vandegrift et al. 2010; Caminade et al. 2014; Ostfeld and Brunner 2015).

Table 1 Climate-impact hypotheses

Climate Impact	Hypothesis
Range shifts	**Species will shift their geographic range in order to stay within their climate niche by moving to different latitudes and altitudes/depths** • Range shifts are expected via cool edge expansions and warm edge contractions • Range shifts will be limited by biological constraints (e.g., dispersal capability, predator/competitor interactions), as well as other barriers (i.e., land use change, physical barriers, migration corridors) • When range shifts cannot sufficiently track environmental changes, local extinctions are expected
Phenological shifts	**Phenology will advance when cued by high temperatures, and will be delayed when cued by cool temperatures. Differing phenological responses will result in temporal asynchrony (i.e., mismatch) between interacting species** • Lower trophic groups are expected to shift their phenology more readily than higher-level consumers creating trophic mismatches between interacting species (i.e., depressed population growth through lowered recruitment; increased population growth through reduced predation) • Migration phenology will be affected, to the extent that organisms are cued by dynamic climate variables rather than static environmental drivers such as photoperiod • Temperature-cued life history stages (i.e., for insects and fishes) will be affected
Phenotypic changes	**Species will adjust their phenotypes through changes in morphology, behavior, physiology, and/or phenology. Species vary in their capacity to adapt** • Where climate change occurs quickly, species with long generation times are not expected to sufficiently track environmental changes • Where climate-induced changes exceed critical thresholds, species are unlikely to sufficiently adapt
Primary productivity	**Primary productivity is expected to increase in response to higher temperatures, although confounding factors (i.e., altered biological communities, secondary consumer dynamics, drought, nutrient availability) may complicate this directional relationship** • Modest to moderate declines in ocean primary productivity are expected, due to increased stratification; regional variations are highly uncertain

(continued)

Table 1 (continued)

Climate Impact	Hypothesis
Invasive species	**The rate of spread and occurrence for invasive species will increase as global climate change accelerates** • Invasive species tend to have life history traits more generally adaptive to rapidly changing environments • Global trade and anthropogenic land use change will increase the spread of facilitate the spread of unwanted plants that grow pervasively and harm desired vegetation • Invasive species will generally outcompete native species in novel or rapidly-changing habitats (i.e., disturbance from extreme weather, drought, and fire) • Management techniques to control invasive species will be outpaced by invasive colonization and spread as climate change accelerates
Novel Communities	**Shifting distributions, abundances, and phenology will result in changing species interactions, novel biological communities, and species assemblages with no historical analogue** • Novel species assemblages will be driven by range shifts in native species and alien invasive species, as well as by phenological shifts • These changes are likely to have a significant impact on ecosystem structure and function

Hypotheses about climate-driven impacts to biodiversity, articulated by the authors based on recent assessments, are presented based on type of impact (range shift; phenological shift; phenotypic change; primary productivity; invasive species; and novel communities). Text in **bold** describes overarching hypotheses that are applicable across ecosystem types (terrestrial; freshwater; marine) and taxa. Text in bullet points describes further explanations for the hypotheses, system-specific details, and/or known exceptions to these overarching hypotheses

Terrestrial Ecosystems

Terrestrial species have shifted their geographic distribution, primarily from low to high latitudes and elevations (Parmesan and Yohe 2003; Moritz et al. 2008; Chen et al. 2011). Temperature-induced latitudinal shifts have been observed in North American birds (Hitch and Leberg 2007) and small mammal communities in the northern Great Lakes region (Myers et al. 2009), while temperature-induced elevational shifts have been observed in American pika *Ochotona princeps* in the Great Basin (Beever et al. 2011) and foraging ants in the southern Appalachians (Warren and Chick 2013). These shifts have principally resulted in contractions at the warm edge of ranges and expansions at the cool edge of ranges (Wiens 2016). However, heterogeneity of distribution responses to temperature may be the result of other climate-related factors (e.g., birds in the Sierra Nevada Mountains; Tingley et al. 2012).

Table 2 Adaptive management strategies

System	Management Response	Example	Reference
Terrestrial	Targeted forest management strategies to counteract effects of drought and fire	North American beaver *Castor canadensis* reintroduction to restore water storage; forest thinning to reduce forest vulnerability to drought and wildfire	Swanston and Janowiak (2012), Crausbay et al. (2017)
	Identify and protect areas of future suitable habitat, climate change refugia, and migration corridors	Protection of large-scale elevation gradients to maintain small-mammal species diversity and ability to migrate to more suitable habitat in Yosemite National Park	Morelli et al. (2016)
	Inclusion of climate-induced changes in species distributions (e.g., mountain pine beetle *Dendroctonus ponderosae*) in large-scale modelling and management	Inclusion of insect outbreaks in large-scale modelling to account for reductions in forest carbon uptake	Kurz et al. (2008)
Freshwater	Increasing riparian shading and groundwater pumping during periods of thermal stress to increase refugia habitat	Proposed thermal refugia management strategies in Miramichi River to enhance and create thermal refugia for cold-water salmon species at their southern margins	Kurylyk et al. (2015)
	Altering watershed manipulations to maintain environmental flows during specific life history events	Strategically store and release water from dams to avoid major flooding or reduced water flows on heavily dammed rivers systems	Palmer et al. (2008)
	Landscape-scale management to maintain important habitat (e.g., maintaining water quality and forest management)	Landscape-level management efforts to protect water quality and forested areas to maintain suitable habitat in Minnesota lakes for coldwater fish	Jacobson et al. (2013)

(continued)

Table 2 (continued)

System	Management Response	Example	Reference
Marine	Reducing anthropogenic stress (e.g., pollution, overharvesting)	Integration of marine reserves into broader spatial planning to address overharvest and pollution threats outside the reserves and reduction of destructive fishing practices (e.g., blast fishing)	Green et al. (2014)
	Adapting protected areas placement, size, and timing	Representation of 20–30% of all habitat types in individual MPAs could help maintain biodiversity and reduce habitat loss; use climate-informed scenarios to assist in selection of protected areas placement	Green et al. (2014)
	Restoration of coastal wetlands, marshes, mangroves and reefs	Planting of salt and flood tolerant marsh species to withstand the impacts of sea level rise	Powell et al. (2017)

Select potential management responses to climate change impacts are provided as examples for terrestrial, freshwater, and marine systems

Freshwater

Freshwater organisms have reduced dispersal capabilities due to the relatively closed nature of freshwater systems (e.g., barriers to upstream and downstream movement, habitat degradation, stream fragmentation and connectivity) (Comte et al. 2013). Depending on physiological thermal limits and preferences, climate change can cause distribution changes of freshwater species to vary in degree and direction (e.g., expansion or contraction) (Lynch et al. 2016). White perch *Morone Americana*, for example, expanded its range in the Great Lakes with warmer air and water temperatures (Johnson et al. 2011), while the range of four Pacific salmon species expanded northward with warmer ocean and summer river conditions in Canada (Babaluk et al. 2000). Documentation of freshwater species shifting ranges is increasing as more freshwater ecosystems are impacted by climate change, having consequences for biodiversity, species composition, and richness (Comte et al. 2013; Myers et al. 2017).

Marine

For marine ecosystems, extensive and contiguous habitat generally allows for shifts in distribution and abundance of species at a faster rate than in terrestrial or freshwater systems in the face of climate change (Nye et al. 2009; Kleisner et al. 2017). Range shifts for marine communities have been observed up to 28 km per decade (compared with 6.1 km in terrestrial systems; Burrows et al. 2011). Projections suggest that range shifts will continue with marine organisms moving to higher latitudes and deeper depths to maintain optimal habitat (Urban 2015). However, ocean currents and ocean chemistry make projecting the potential for range shifts in marine species more complex than movement driven solely by temperature (Harley et al. 2006). Additionally, organisms in stable environments, such as marine tropical systems, often have much narrower niche bounds and may not be able to migrate at a rate comparable to environmental change (Walther et al. 2002).

Phenological Shifts

Climate change is expected to alter the phenology of most species across ecosystem types. Earlier springs have been well documented (Ault et al. 2013), and increasingly studies have focused on delays in the onset of autumn as well (Gallinat et al. 2015). A wide range of organisms have demonstrated phenological shifts in response to these changes (Thackeray et al. 2010), although these responses vary across taxonomic and trophic groups (Thackeray et al. 2016), as does our ability to detect such changes. Generally, species in lower trophic levels are expected to advance their phenology more than higher trophic consumers (Thackeray et al. 2010). These differences will likely result in altered species interactions and will have implications for species fitness and production, particularly for populations of vulnerable species (Møller et al. 2008; Peer and Miller 2014) like pollinators (Memmott et al. 2007) and salmonids (Kovach et al. 2015b). Phenological shifts, and consequent trophic mismatches, are often difficult to account for in single-species management structures but they are necessary to consider for a comprehensive assessment in informing adaptive management (Lawler 2009).

Terrestrial

Phenological shifts and associated mismatches have been well-documented in terrestrial systems, such as those between plants in the prairie-forest transition areas of the Midwest and their pollinators: the plants are at increased risk of extinction because pollinators are arriving after peak bloom, minimizing the likelihood of pollination of plants and reducing the diet breadth of pollinators (Memmott et al. 2007). Organisms do not universally respond to phenological drivers in the same way; when phenological shifts manifest differently, they can result in mismatched or insufficient responses. Broad-tailed hummingbirds in Arizona and Colorado, for example, have not advanced their arrival date sufficiently to track the advancing phenology of their primary nectar sources (McKinney et al. 2012).

Freshwater

Phenological shifts resulting from changes in temperature and flow have been documented for a variety of North American fish species; because detection is often easier in coldwater habitats, the literatures focuses mainly salmonid species (Kovach et al. 2015b; Lynch et al. 2016; Myers et al. 2017). Earlier spawning migrations are documented in salmon species in Alaska and Washington (Quinn and Adams 1996; Kovach et al. 2013, 2015a) and Rio Grande fish assemblages in New Mexico (Krabbenhoft et al. 2014). These phenological changes have impacts on freshwater ecosystem biodiversity by affecting food web dynamics, organism demographics (e.g., abundance and growth), and species composition (Lynch et al. 2016). These changes can result in mismatches in resource availability and impact ecosystem functioning and services.

Marine

Alterations in phenology are perhaps the most evident climate response in rapidly changing marine systems (Asch 2015). Shorter winters, earlier springs, and extended summers are occurring in some marine systems (Edwards and Richardson 2004; Robinson et al. 2014; Henderson et al. 2017; Thomas et al. 2017), resulting in shifts in the early life stages of commercially important groundfish (Klein et al. 2017), Northern shrimp *Pandalus borealis* (Richards 2012), and highly migratory anadromous fishes such as Atlantic salmon *Salmo salar* and river herring *Alosa* spp. In the northeastern United States (Juanes et al. 2004; Ellis and Vokoun 2009; Otero et al. 2014), mismatches can arise when trophic levels respond to climatic cues differently. For example, larval fish have evolved synchronized hatching with seasonal marine phytoplankton blooms; if the bloom and hatch are decoupled, the larval fish may miss this critical food source (Post 2016; Sundby et al. 2016).

Phenotypic Changes

Species may have some ability to cope with climate change by adjusting their traits through plastic or evolutionary mechanisms so they can better tolerate changing environmental conditions and reduce risk of population declines or local extinctions. Specifically, changes in morphology, behavior, or physiology may increase fitness, but those adjustments are more commonly the result of phenotypic plasticity rather than evolution (Merilä and Hendry 2014), particularly for species with long generation times. Therefore, it is likely that many species will be unable to keep pace with rapid climate changes in situ (Staudinger et al. 2013).

Terrestrial

There is some documentation of plastic and evolutionary responses to climate change in terrestrial species. Snowshoe hares *Lepus americanus* are plastic in the timing of their coat color changes from white to brown in spring in response to early snow melt, making them less susceptible to predation (Zimova et al. 2014). Evolutionary change has been observed in *Brassica rapa L.* sampled from southern California, which began flowering earlier to minimize the impact of shorter growing seasons as the result of increased drought impacts (Franks 2011). Numerous other organisms, including the American pika, have demonstrated the capacity to alter their behavior in order to adapt to changing habitat conditions (Beever et al. 2017).

Freshwater

Documented responses of fish to climate change reveal the ability of freshwater organisms to adapt to changes in climate conditions through multiple pathways, offsetting species loss and providing some resilience to freshwater ecosystem function (Elmqvist et al. 2003; Kovach et al. 2015b; Lynch et al. 2016). For example, Kovach et al. (2012) found evidence of an evolutionary response in migration timing of pink salmon *Oncorhynchus gorbuscha* into freshwater habitats in response to stream temperature increases and shifting ocean conditions using long-term genetic data. Although temperature preferences and thresholds are known for some freshwater fish species and phenological and range shifts have been observed (Lyons et al. 2009; Alofs et al. 2014; Krabbenhoft et al. 2014), increased temperatures or shifts in flows past critical temperature or water level thresholds may ultimately exceed plastic or evolutionary responses and result in reduced ability to adapt.

Marine

In a critical review of the plastic and evolutionary responses to climate change in fish, Crozier and Hutchings (2013) note numerous examples of phenotypic responses of fishes to climate change but only two formally include evolutionary mechanisms for an anadromous species, sockeye salmon *O. nerka* (Crozier et al. 2011; Kovach et al. 2012). While the trends were considered adaptive for some life stages, adaptive capacity was not explicitly examined in these studies. However, if evolutionary changes are to occur, they may act to reduce animal body size and life span, which would reduce their value for fisheries (Sheridan and Bickford 2011).

Changing Primary Productivity

As primary production is driven, at least in part, by temperature, climate change is expected to increase productivity in terrestrial, freshwater, and marine systems. Projected increases, however, are not always realized since confounding factors, such as sunlight, nutrient loading, and secondary consumer interactions can influence actual production rates in dynamic and non-linear ways (Brown et al. 2010; Rykaczewski and Dunne 2011; Zhu et al. 2016). An understanding of climate change implications for primary production rates is particularly important for biodiversity management planning because primary productivity impacts ecosystem function and structure across trophic levels (Carpenter and Kitchell 1992).

Terrestrial

While terrestrial primary production has increased globally with climate change (Campbell et al. 2017), factors such as regional climate and land use changes cause primary production trends to vary across the U.S. (Zhu et al. 2016). Worsening droughts in the Southwest, for example, have decreased primary production in that region (Zhang et al. 2013) and models suggest that decline will continue in the future (Reeves et al. 2014). As a result, those areas may undergo large changes in community composition and species diversity (Polley et al. 2013; Fritz et al. 2016). Other regional factors, such as mountain pine beetle *Dendroctonus ponderosae* outbreaks in western North America, have shown to decrease primary productivity of certain tree species. Although the beetle is native to the region, warmer winters have increased survival and exacerbated outbreaks in some regions, affecting the ability of northern forests to take up and store carbon (Kurz et al. 2008).

Freshwater

Climate-induced floods and changes in flow, temperature, and cloud cover influence freshwater ecosystem plankton, macrophytes, primary production, and nutrient cycling (Carpenter and Kitchell 1992). Primary production can increase after extreme precipitation events due to large amounts of nutrient runoff, leading to eutrophication and hypoxic conditions in lakes. Reduced oxygen levels in turn have negative impacts on fish and other freshwater organisms (Schindler et al. 1990). Melack et al. (1997) predicted increased glacial runoff from climate change would reduce primary production and ultimately cause decreased growth in salmon in southcentral Alaska. The impacts of climate change on freshwater primary production affects ecosystem function on multiple levels (Elser et al. 2007).

Marine

Marine primary production is driven by light and nutrients and is moderated by temperature. With climate change, there is increased stratification between the surface and deeper layers which can limit nutrient availability at the surface (Stocker 2014), as well as projected changes to salinity (Saba et al. 2016). Direct evidence for declines in primary productivity as a result of climate change, however, remains mixed (Henson et al. 2010; McQuatters-Gollop et al. 2011; Boyce et al. 2014). Modest to moderate declines in ocean primary production are projected for most low- to mid-latitude oceans over the next century, but regional patterns of change are less certain (Rykaczewski and Dunne 2010; Bopp et al. 2013; Laufkötter et al. 2015). Most models also project increasing primary productivity in the Arctic due to decreasing ice cover, which is supported by recent observations (Arrigo et al. 2008; Vancoppenolle et al. 2013; Ardyna et al. 2014).

Invasive Species

Climate change and non-native species are both recognized as significant drivers of biodiversity loss (Hellmann et al. 2008). Novel climate conditions and biotic selection pressures are generally expected to favor invasive species over short evolutionary timescales (Moran and Alexander 2014), although locally adaptive traits and competition for resources can also favor native species (Sorte et al. 2013). A changing climate, in conjunction with increased global trade, is generally expected to favor the establishment and spread of biological invasions, but the condition of the habitat and ecosystem structure (i.e., species richness and diversity) will also impact establishment. Direct evidence, however, is still lacking for many taxa (Hulme 2017).

Terrestrial

Extreme climatic events, such as storms, floods, or droughts, can facilitate the transport, establishment, and spread of terrestrial invasive species, as well as affect the magnitude of their impacts (Diez et al. 2012). Many of the same 'weedy' traits (e.g., pervasive growth) associated with invasive species put them at an advantage with respect to climate change tolerance and adaptability. For example, introduced cool-season grasses can respond strongly to extreme precipitation events, which has drastically altered the plant community composition in a Colorado mixed-grass prairie (Concilio et al. 2016).

Freshwater

Climate change coupled with the presence of invasive species in freshwater ecosystems has compounding impacts on native diversity (Rahel and Olden 2008). A recent review of aquatic invasive species found that recent invasions are more well-documented for terrestrial systems compared to freshwater (Havel et al. 2015). Nonetheless, climate change is thought to have allowed the invasion of two tropical, invasive dragonflies to freshwater systems in Florida (Paulson 2001). Presence and increased abundance of invasive species resulting in alterations of the food web (see Zanden et al. 1999) and more competition for resources impact native freshwater species and biodiversity (Lynch et al. 2016).

Marine

Non-native species are often introduced into marine systems via transportation, commerce, and other human-assistance pathways, but natural spread is an increasingly common pathway due to changing conditions (Molnar et al. 2008). The range expansion of invasive species due to climate change has been proposed as a mechanism for increasing successful invasions (Occhipinti-Ambrogi 2007). The effect of climate change and invasive species has been implicated in the expansion of invasive European green crab *Carcinus maenas* from the Gulf of Maine to Nova Scotia (Roman 2006), as well as in the collapse of marine ecosystems, such as in the Gulf of Maine, where declines in groundfish stocks have been attributed to overfishing, introduction of opportunistic benthic species, and a 1–2 °C increase in sea surface temperatures (Harris and Tyrrell 2001).

Novel Communities

Novel communities and ecosystems are predicted to become increasingly common as native species shift their ranges, new species invade areas outside their historical ranges, and species shift their phenology patterns (Lynch et al. 2016). Novel communities have been documented in terrestrial (Morgado et al. 2015), freshwater (Krabbenhoft et al. 2014), and marine ecosystems (Edwards and Richardson 2004; Smith et al. 2017). Novel communities will present new challenges to biodiversity management efforts and create difficult questions and decisions on how best to manage these new climate change-induced assemblages.

Terrestrial

New combinations of terrestrial species are already being observed in many parts of the U.S., particularly where warming is more rapid. Fungal community structure is shifting in the moist tundra regions of Alaska so that warm-adapted species are becoming more common, potentially affecting nutrient cycling and carbon storage (Morgado et al. 2015). Additionally, warming temperatures have reshuffled winter bird community structure in the eastern U.S. as a result of increasing abundance and colonization of smaller-bodied and warm-adapted birds (Princé and Zuckerberg 2015). Invasive cheatgrass *Bromus tectorum* in sagebrush-steppe habitats in the western U.S. is creating novel conditions (Bradley et al. 2006) that are disrupting trophic interactions between large mammalian predators (e.g., American badger *Taxidea taxus*) and their prey (e.g., Piute ground squirrel *Urocitellus mollis*; Holbrook et al. 2016).

Freshwater

Climate-induced range shifts, invasive species colonization, changes to primary production, and varying levels of adaptive capacity may result in novel freshwater communities and ecosystems with new species functioning differently (Lynch et al. 2016). For example, southeastern U.S. freshwater systems are particularly vulnerable to climate change effects in high diversity streams and lakes (Mulholland et al. 2008). Climate-induced changes in flow result in less diverse macroinvertebrate communities made up of species with shorter life histories, such as mayflies, outcompeting species with longer life history traits (e.g., mollusks) (Mulholland et al. 2008).

Marine

Climate change-driven range shifts and introduction of invasive species can lead to new species interactions and novel communities within marine systems. Often, these new scenarios can have negative implications for native species. Residence time for tropical species in the temperate estuaries of Narragansett Bay and Long Island Sound has increased with climate change to the point where some species are becoming more established; this has significant implications for commercial fisheries, as these habitats are nursery grounds for many commercial fish species and the tropical species can predate on the fry and also compete for valuable resources (Wood et al. 2009).

Management Responses and Broader Implications

As climate change increasingly affects biota and ecosystems around the world, evidence is accumulating for both anticipated and unanticipated effects. Nevertheless, many knowledge gaps and uncertainties remain, particularly at local and regional levels. The speed of this global, unprecedented change and associated uncertainties require rapid, ongoing dialogue between managers and scientists to ensure informed management of impending risks to valued resources. However, many projected impacts to biodiversity have not yet been tested or are occurring inconsistently across taxa and among ecosystems. Here, we reviewed evidence for climate impacts to biodiversity from recent literature and climate assessments in the U.S. for the purpose of constructing general working hypotheses.

We articulated common hypotheses about expected range shifts, phenological shifts, phenotypic responses, changes to primary production, biological invasions, and development of novel communities to climate change (Table 1), and attempted to provide a basic assessment framework for understanding observed climate change impacts to biodiversity. We articulated these hypotheses based on literature reviews we conducted during recent assessments, and based on our subject matter expertise. It is important to note that conducting a systematic literature review for each hypothesis was outside the scope of this paper, as was articulating hypotheses on a regional- or system-specific scale. Ultimately, this set of hypotheses can be most useful as a generalized framework, within which the research community can iteratively assess impacts and refine hypotheses in light of new evidence. Repeated evaluation of observed impacts through modelling and assessment are essential to describing the underlying processes driving climate change impacts within global ecosystems. Flexible, adaptive management approaches can use this information to prepare for projected impacts of climate change while accounting for significant uncertainty (Table 2). Moving forward, this effort will benefit from a formal, quantitative assessment of evidence for each hypothesis through a systematic literature review and expert elicitation, particularly to examine impacts at regional scales. In addition, work connecting the observed and projected impacts of climate change, as understood through these hypotheses, to effects on ecosystem goods and services and associated co-benefits would provide valuable information to decision makers and managers. By using a hypothesis-driven framework to understand climate impacts to biodiversity, the scientific community can better inform climate adaptation actions and associated management strategies.

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Significance of Protected Area Network in Preserving Biodiversity in a Changing Northern European Climate

Raimo Virkkala, Risto K. Heikkinen, Saija Kuusela, Niko Leikola and Juha Pöyry

Abstract Climate change is a major threat to biodiversity, causing species to move to new climatically suitable areas, and thus increasing the extinction probability of species inhabiting fragmented landscapes. This highlights the need for climate-wise conservation strategies. With such strategies, a well-connected network of protected areas (PAs) is one of the most important means to support species survival. An extensive and representative PA network can enhance the resilience of regional populations of species, resulting in slower species loss in landscapes with a significant proportion of area of habitat being protected. This paper presents analyses of both the observed (1974–2010) and the predicted changes (by 2051–2080) in boreal bird populations in Finland. Firstly, the results show some general patterns of climate change on bird species: (1) species are shifting their ranges towards north, (2) range sizes of many species are declining, and (3) these changes are different in northern and southern species and in species occupying different habitats. Secondly, the paper looks more into the role of protected area (PA) network in securing birds in a changing climate and concludes that at least in Finland, open habitats, such as open mires and mountain heaths, change more rapidly in their species composition in protected areas than for example old-growth forests. However, generally, species decline less within than outside PAs showing that protected areas alleviate climate change effects on bird species of conservation concern. This finding, further supported by results from elsewhere in Europe, provides evidence for the resilience of PA networks in preserving species under climate change. Representative PA network that includes high cover for key habitats is hence needed in all latitudinal zones. The projected efficiency of the PA network in maintaining biodiversity was partly dependent on the strength of climate change varying with respect to future scenarios. This suggests

R. Virkkala (✉) · R. K. Heikkinen · S. Kuusela · N. Leikola · J. Pöyry
Biodiversity Centre, Finnish Environment Institute, P.O. Box 140, FI-00251
Helsinki, Finland
e-mail: raimo.virkkala@ymparisto.fi

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that a flexibly adaptive climate-wise conservation planning is required to be better prepared for preserving biodiversity in the face of uncertain climate change. Thirdly, the paper discusses several aspects of climate change studies and avian biodiversity that have been hitherto understudied especially in the northern biomes. The paper suggests that future studies should concentrate on (1) abundance-based models and prioritisations, (2) species' adaptive capacity (ability to avoid the impacts of climate change through dispersal and/or evolutionary change) and sensitivity (limited potential to persist in situ under changing climate) to climate change, (3) the role of the landscape matrix around the PAs and (4) the effects of the biogeophysical features of the PAs themselves. In conclusion, we envision that improved assessments regarding the ability of PA networks to maintain biodiversity in northern biomes are needed to enhance our ability to perform climate-wise conservation planning.

Introduction

Global climate change is one of the most important threats to biodiversity (Bellard et al. 2012; Thomas et al. 2004), creating accelerating pressures on species populations and communities (Parmesan 2006; Pacifici et al. 2017). Future changes in climate are projected to cause large changes in the distribution of species in various taxa (Thomas et al. 2004; Thuiller et al. 2005). For example, bird species distributions have been projected to change considerably in Europe during the 21st century (Huntley et al. 2007, 2008). Climate change also causes a notable turnover in species and alters the functional structure of species assemblages (Thuiller et al. 2014; Virkkala and Lehikoinen 2017).

One of the main instruments alleviating the impacts of climate change on biodiversity are regional and national networks of protected areas (PAs). However, species ranges are moving poleward following the effects of changing climate (Parmesan 2006; Huntley et al. 2007, 2008; Brommer et al. 2012), which poses challenges for the PA networks, possibly decreasing their efficiency at preserving biota (Araújo et al. 2004; Hannah et al. 2007). Under shifting species distributions, PAs may cease to provide protection to those species for which they were originally established (Coetzee et al. 2009; Hole et al. 2009; Araújo et al. 2011).

The future efficiency of the PA network in preserving biodiversity under a changing climate has been studied using modelled projections of species range shifts, and by comparing climatically suitable areas for the species at present and in the future (Hannah et al. 2007; Hole et al. 2009; Araújo et al. 2011). Such studies, employing so-called bioclimatic envelope models (BEMs), have provided important insights into potential species losses, turnover and gains in conservation areas, as well as gaps in the PA network (Heikkinen et al. 2006; Araújo and Peterson 2012).

Climate change-driven range shifts are expected to be the most pronounced at northern latitudes because of the greater temperature increase projected for these regions (Jetz et al. 2007). For example, in Finland, according to the strongest climate change scenario, the mean annual temperature will increase by as much as 7 °C by

2080 in comparison with the baseline period, 1961–1990 (Jylhä et al. 2004). Loarie et al. (2009) compared the world's 14 main biomes and their PAs, demonstrating that the so-called climate residence time will be among the lowest for PAs situated in boreal forests by the year 2100. This would mean that the PAs of boreal forests are likely to face the greatest climatic changes on a global scale. Moreover, species and communities in northern boreal and Arctic regions are at particular risk because the Arctic Ocean represents an effective natural barrier to northward range shifts. Virkkala et al. (2008) showed that bird species particularly susceptible to the effects of climate warming are indeed those with distributions concentrated in the northern boreal or Arctic zones.

Given these forecasts, the magnitude of species turnover in the PAs of a boreal biome may be extensive following the large local and regional changes in climatic suitability for the species, i.e. northern species retreating northwards will be replaced by new species from the south. The need for assessments of the impacts of climate change on boreal biota is urgent due to the fact that landscapes and environments in northern Europe are also affected by diverse land use causing the degradation of habitats, such as intensive forest management, drainage of mires and wetlands, and ultimately, fragmentation of a previously continuous forest landscape.

In this paper we first (Sections "General Patterns of Climate Change Effects on Bird Species in Finland" to "Range Shifts of Birds in Relation to Dispersal Patterns") summarise findings from recent studies on bird species distributional and density pattern changes with respect to PA network in northern Europe, and then (Section "Directions for Future Research") discuss a number of insufficiently studied research questions with respect to the conservation of birds in the changing northern environments. In the first sections, key findings come from our analyses of both the observed (1974–2010) and predicted changes (by 2051–2080) in boreal bird populations in Finland. Here, we will first assess whether the distributional changes of species are in line with the predictions of the climate change and secondly, if the changes are more pronounced in unprotected than in protected areas, i.e. whether a PA network can be resilient in relation to climate change in preserving species of conservation concern. In other words, the paper sheds light on the question of how well will the current PA network maintain bird species populations in the future given a rapidly changing northern European climate. In Section "Directions for Future Research" we discuss future prospects of species and PA vulnerability assessments which can be used in developing climate-wise protected area networks. Conclusions are presented in Section "Conclusions". The paper focuses on birds and studies performed in northern Europe. Thus, the conclusions may not hold in other species groups with different life histories and dispersal abilities, or in birds living in other locations with possibly less severe climatic changes and anthropogenic pressures.

General Patterns of Climate Change Effects on Bird Species in Finland

Finland stretches 1100 km across the boreal biome of northern Europe and is latitudinally divided in the hemiboreal, southern boreal, middle boreal and northern boreal zone, with the northernmost parts of northern boreal being at the border of the subarctic zone (Fig. 1). PA network is largely concentrated in the northern boreal zone and is mostly covered with coniferous (dominated by Scots pine *Pinus sylvestris* or Norway spruce *Picea abies*), mixed and deciduous (dominated mainly by birch *Betula* spp) forests, open mires (treeless peatlands), marshlands, and Arctic mountain heaths.

In Finland, the mean weighted latitude of the observed population density of the 94 most common land bird species has moved northwards, on average by 1.3 km year^{-1} from the 1970s to the 2010s (Virkkala and Lehikoinen 2014). The shift was more pronounced in northern species than in southern ones, but range shift based on presence-absence atlas data was more rapid in southern than in northern species (Brommer et al. 2012; Virkkala and Lehikoinen 2014). The difference can be explained by the methodology that was used: in the atlas data the extinction from a given grid cell at the species' southern range margin can be a slow process with a small bird population surviving for some time. Similarly, in Sweden the composition of boreal bird assemblage has been shown to respond to temperature changes with a time lag of 1–3 year(s) (Lindström et al. 2013).

Studies based on BEMs using presence-absence bird atlas data from 1974 to 1989 have suggested that northern-boreal bird species may face range contractions of 74–82% by 2080 depending on the climate scenario for northern Europe (Virkkala et al. 2008). Observed range shifts provide support for these predictions: the ranges of northern-boreal bird species that were predicted to contract by 2080 had already declined by 27% from 1974–89 to 2006–10 (Virkkala et al. 2014a)

Based on the Finnish national bird atlases compiled in 1974–1989 and 2006–2010, the recent range shifts in forest, mire, marshland and Arctic mountain heath bird species of conservation concern [including e.g. red-listed species, EU Bird Directive species (Annex I), species of European conservation concern; see Virkkala et al. (2013a) for details], as well as the changes in their species richness in protected versus unprotected areas were compared (Virkkala et al. 2014b). The trends emerging from the atlas data comparisons were also related to the projected distributional changes of these species for the time slice of 2051–2080 (Virkkala et al. 2013a, b). The results suggest that the observed changes in bird distributions are in the same direction as the BEM-based predictions, resulting in a decrease in species richness of (northern) mire and Arctic mountain heath species and an increase in (southern) marshland species.

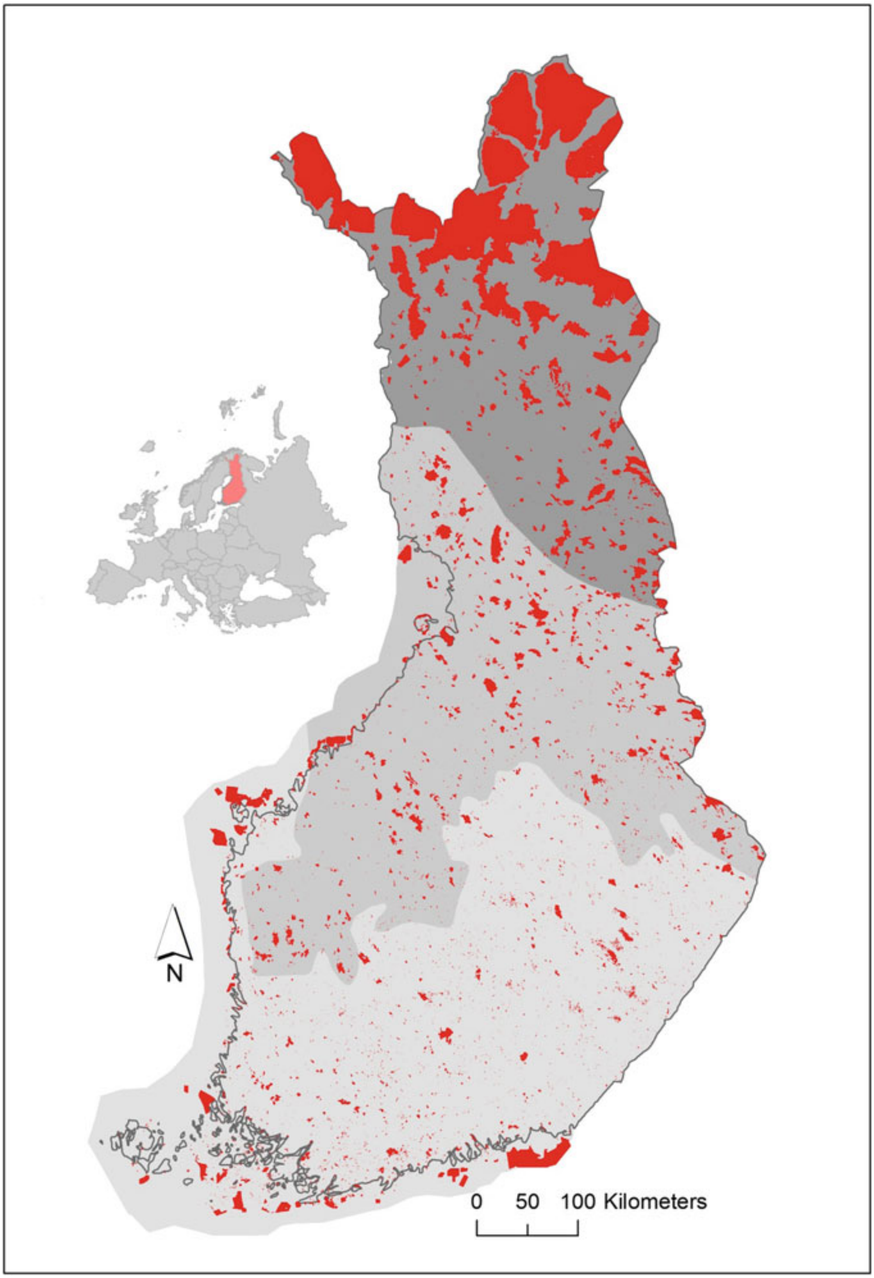

Fig. 1 Location of protected areas (red) in Finland. Light grey = southern boreal zone, middle grey = middle boreal zone and dark grey = northern boreal zone. Hemiboreal zone in the south-western coast is included in the southern boreal zone

The Role of Protected Areas in Preserving Bird Species Populations

Virkkala and Rajasärkkä (2011a) examined changes in bird populations in a set of 96 Finnish PAs based on transect count observations. Their results showed that populations of southern species had increased by 29% while those of northern species had declined by 21% between 1981–1999 and 2000–2009. These changes were most pronounced near the species range boundaries: southern birds increased most in northern PAs and northern species decreased most notably in southern PAs (Virkkala and Rajasärkkä 2011b). In particular, species breeding on open mires and in Arctic mountain heaths in northern Finland have decreased. It appears that species inhabiting PAs where the focal habitats may change rapidly because of climate change (e.g. open mires and mountain heaths) have more difficulties in maintaining their populations than species occupying PAs where the time lags in climate change-induced habitat alterations are longer (as in old-growth forests) (Virkkala and Rajasärkkä 2012).

The observed changes in species richness between the two time slices (1974–1989 and 2006–2010) were in general parallel in protected and unprotected areas. However, protected areas maintained a higher level of species richness than unprotected areas (Virkkala et al. 2014b). Moreover, when examining the population density changes of bird species, it appears that northern cold-adapted species have declined much less within than outside PAs (Santangeli et al. 2017). These findings provide support for the significance and resilience of PA networks in preserving species diversity under climate change. Similar results were also presented in France, demonstrating that the more a bird species benefited from PAs, the less vulnerable it was to temperature changes (Gaüzère et al. 2016).

Within the boreal zone, the ranges of species of conservation concern are predicted to shift dramatically during the 21st century. For example, the ranges of forest species (measured as probability of occurrence) currently situated in the southern boreal zone are predicted to move towards the middle and northern boreal zones (Virkkala et al. 2013a). The ranges of all species groups occurring in different habitats (except marshland birds) are predicted to decrease by 2051–2080, with the decline being greatest in southern boreal and smallest in northern boreal zone. This is because species presently occurring in the southern boreal zone are predicted to move to the northern boreal zone partly compensating for the predicted decline of the northern boreal species. In contrast, southern Finland is projected to face a general decline in southern boreal birds. This is because species found e.g. in the Baltic countries will apparently not be able to compensate for the projected losses in southern Finland. Thus, the ranges of the species are predicted to shift northwards, but the potential gain of expanding southern species of conservation concern (occurring presently south of Finland) will apparently not compensate for the loss of the present boreal species. Overall, a high bird species turnover is predicted to occur in the 21st century and was already observed in Finland between 1974 and 2010 (Virkkala and Lehikoinen 2017). For species living in forests, mires and mountain habitats, the changes are predicted to be slightly greater in unprotected than in protected areas. Thus, a representative PA network that includes high cover for key habitats is needed in all latitudinal zones.

Virkkala et al. (2013b) expanded on the finding of earlier studies by relating bird species occurrences to the amount of habitat preferred in the PAs in the different boreal zones. Here, a novel integrated habitat suitability index was employed to account jointly for the projected species' probability of occurrence and the availability of suitable habitat (Virkkala et al. 2013b). Based on this suitability index, the distribution of suitability hotspots (topmost 5%) were determined for birds living in forests, open mires, marshlands and Arctic mountain heaths in 1971–2000 and under three climate change scenarios (IPCC SRES scenario: B1, A1B, A2). The locations of the suitability hotspots were compared with the locations of reserves with the greatest amounts of the four habitats to assess the efficiency of the PA network. For species inhabiting mires, marshlands and Arctic mountain heaths, a high proportion of protected habitat was included in the 5% hotspots in the scenarios for 2051–2080, showing a good match between current PAs and suitability hotspots in 2051–2080. In contrast, in forests in the southern and middle boreal zones, only a small proportion of the protected habitat was included in the 5% hotspots, indicating that the efficiency of the current PA network will be insufficient for forest birds in the future (Virkkala et al. 2013b). This is because only 2.3% in the southern boreal zone and only 3.7% in the middle boreal zone are included in the protected areas whereas 23% of forests in the northern boreal zone are protected (Virkkala et al. 2013a).

In the northern boreal zone, the predicted efficiency of the reserve network in forests was highly dependent on the forcefulness of projected climate change. In the northern boreal zone the extent of PAs is much higher than in the south (see Fig. 1), but due to the concentrated location of the areas, the significance of PAs for maintaining forest bird species (of conservation concern) emerges particularly under the strongest scenario: A2 (Virkkala et al. 2013b). The concentrated level of forest protection in the northernmost part of the northern boreal zone raises an interesting dilemma: in a mild climate change scenario, the PA network is clearly inefficient, while in a strong climate change scenario it preserves, on average, species occurrences much more effectively precisely because southern forest species are expected to move more towards the north as a result of climate change (Virkkala et al. 2013b). However, the extinction of northern species should be the most profound according to the strongest climate change scenario (Virkkala et al. 2008). Thus, there is no single solution for preserving biodiversity in a changing climate, but several future pathways should be considered.

Range Shifts of Birds in Relation to Dispersal Patterns

PAs have been observed to facilitate the species' range expansions of various species (Thomas et al. 2012), which is a key issue when analysing the future significance of PA networks for biodiversity given a changing northern European climate. Individual PAs can act as stepping stones for creating a suitable breeding habitat (Thomas and

Gillingham 2015). In Finland, certain habitats, such as old-growth forests and many mire and wetland types, can nowadays only be found in PAs due to intensive forestry and other land use practices outside PAs. For species specialised to these habitats, the PA network is indispensable.

The dispersal ability of bird species is, in general, fairly good in relation to many other species groups, although certain resident forest species can be quite poor dispersers [e.g. Siberian jay *Perisoreus infaustus* (Griesser et al. 2014)]. Good dispersal ability of individual birds enables shifts in a species range, but intensive land use leading to the degradation and fragmentation of habitats may restrict bird species range shifts following the effects of climate change (see Virkkala and Lehikoinen 2017). In addition to northern species (such as the Siberian jay), some southern bird species have also declined and their ranges have retreated. This may suggest that not all southern species may track climate change due to the scarcity of suitable habitat north of their present range. In general, species richness is predicted to increase in the northern latitudes as more southern species expand their ranges northwards (see Huntley et al. 2007). However, in Finland the total amount of bird species richness did not change in 10 km grid cells in a clearly warming period from 1974–1989 to 2006–2010. Thus, southern species have not expanded as quickly as might be expected as a result of climate change (Virkkala and Lehikoinen 2017; for the future predictions of southern species, see Section "The Role of Protected Areas in Preserving Bird Species Populations"). Moreover, in Finland 128 land bird species shifted their mean weighted densities between 1970–1989 and 2000–2012 by 37 km to the north north-east while the mean annual temperature shifted on average 186 km in the same direction. Thus, the speed of climate change is occurring almost five times more quickly than the speed of density shifts (Lehikoinen and Virkkala 2016).

Directions for Future Research

Abundance and Vulnerability Studies

The studies discussed above have mainly examined the recent range shifts in bird species, or forecasted future distributions using bioclimatic envelope models (BEMs). Studying the magnitude of projected changes in remaining, new and overlapping (present-future) suitable areas allows to asses species' exposure to the effects of climate change (Foden et al. 2013; Reside et al. 2016). However, while BEMs provide useful estimates of potential changes, forecasts for the relative suitability of different regions and individual PAs for a species may be improved by including measures of abundance in the models (Howard et al. 2014). Importantly, abundance-based models assist in the identification of PAs, which can harbour sufficiently large populations, thus lowering the local extinction risk. Such models have been applied to birds in the UK, revealing vital insights into the projected future population declines of species and the long-term representativeness of PAs (Johnston et al. 2013). In northern biomes, abundance-based data prioritisations of current and future important areas for bird conservation are still lacking, constituting one obvious knowledge gap. Data permitting, the inclusion of breeding success in the bird species models would also make it easier to identify PAs with the highest potential for long-term population persistence (Suárez-Seoane et al. 2017). However, the collection of breeding success data may need to be targeted to particular species of conservation concern due to the considerably high resource demands.

It is increasingly acknowledged that climate change exposure assessments for species should be complemented with an examination of two other vulnerability measures: species' adaptive capacity (ability to avoid the impacts of climate change through dispersal and/or evolutionary change) and sensitivity (limited potential to persist in situ under changing climate) to climate change. In a case-in-point study, Foden et al. (2013) developed vulnerability assessments for the world's 9856 bird species. In their work, sensitivity was determined based on characteristics such as habitat specialisation, narrow environmental tolerance and rarity, low adaptive capacity based on, e.g. poor dispersal potential, and limited evolutionary potential due to, e.g. low genetic diversity or low reproductive output. Bird studies focusing on certain biomes (Reside et al. 2016) or regions (Case et al. 2015) have largely employed similar vulnerability criteria, along with some other criteria, such as dietary breadth and species' physiological sensitivity. Corresponding studies from northern biomes are largely lacking. Clearly, new studies on this topic could help in assessing which bird species are among the most vulnerable in boreal environments and which life history traits make them sensitive in the face of climate change. For example, although birds are more mobile than many other species groups, there are between-species differences in their dispersal ability, potentially affecting their range expansion capacity and colonisation of isolated PAs (Huntley et al. 2008; Reside et al. 2016).

Two take-home messages emerge from the vulnerability studies. First, a species may be vulnerable due to its limited adaptive capacity or high degree of sensitivity, even if it is only slightly exposed to climate change, and also due to other combinations of vulnerability criteria. Most importantly, sole exposure-based assessments may either overestimate or underestimate climate change impacts, and different perspectives are required to reveal hidden vulnerabilities (Reside et al. 2016). Second, the combined use of three criteria makes it possible to identify the species most at risk, i.e. species that are highly sensitive, that are highly exposed and that have lowest adaptive capacity (Foden et al. 2013). Such information facilitates targeting conservation interventions not only for the most vulnerable species, but also for the areas and PAs harbouring the largest concentrations of those particular species. Trait-based analysis can also be linked to observed changes in species distributions (Pacifici et al. 2017). Thomas and Gillingham (2015) reviewed the numerous positive cases of species being able to colonise new PAs; such information could also be linked with species' life histories to determine traits that either support the colonisation of new areas or severely obstruct it.

Habitat preferences of bird species may limit their ability to adapt to climate change not only because of their fidelity to a specific habitat but also due to differences in the rate of projected habitat changes relevant for the species. For example, forest dwelling species are not generally subjected to rapid environmental changes in protected forests, but, on the other hand, the colonisation of old-growth forest may be delayed in currently sparsely wooded PAs due to the slow succession rate of forests. In contrast, the overgrowth of open alpine areas and grasslands is a rapid process which has been considered as one key threat to open habitat bird species (Chamberlain et al. 2013) (see also Virkkala and Rajasärkkä 2012 and Section "The Role of Protected Areas in Preserving Bird Species Populations" above).

Importance of Matrix and Protected Areas' Characteristics

Assessing the representativeness of PA networks in a changing climate requires research also on two other topics: the landscape matrix around the PAs and the biogeophysical features of the PAs themselves. Häkkilä et al. (2017) examined the effects of land use intensity in the surrounding matrix on the diversity of bird species in boreal PAs. They showed that low intensity forest management in the matrix supported the well-being of a wide range of specialised bird species in the PAs, indicating the challenges for boreal forest reserves to maintain the full range of bird diversity in degraded landscapes. Similar studies could also be conducted for other northern ecosystems, including peatland, wetland and alpine communities in the PA network. Equally important would be more in-depth examinations of the impacts on the quality of a dynamically changing matrix and its interactions with climatic change, as these two drivers may jointly have amplified effects on the efficacy of PAs (Sieck et al. 2011). Indeed, Beale et al. (2013) have shown that while recent spatial changes in climatically suitable areas have driven the broad patterns of distributional changes, colonisation preferentially occurs in less degraded areas with a higher proportion of PAs. Land use scenarios indicate that many PAs are likely to lose natural vegetation in their surroundings due accelerating human impacts (Gimona et al. 2012; Martinuzzi et al. 2015). These prospects highlight the importance of buffering PAs (Sieck et al. 2011) but they also identify the PAs which are projected to be hardest hit by the joint impacts of matrix and climate change.

Intensified land use in the matrix may also have negative impacts on species' ability to move to the new PAs as suitable habitats become more fragmented and isolated in the intervening landscape (Sieck et al. 2011) and the overall ecological connectivity of the network deteriorates (Gimona et al. 2012). A key target for climate-wise species conservation is the planning of a network of readily reachable, biodiversity-friendly managed sites that can serve as stepping stones in the process (Huntley et al. 2008). The importance of such a stepping stone or metapopulation network depends on species' dispersal ability, which is more critical for resident birds and species with low gap-crossing propensity than for migratory birds (see also Section "Range Shifts of Birds in Relation to Dispersal Patterns"). However, further research is required on how dispersal ability, in association with other important traits, such as habitat specialisation and sensitivity to temporal weather perturbations, affect species' range shifting and colonisation processes across the dynamically altering matrix and under varying climatic conditions. Such studies would make it possible to determine areas where the landscape matrix severely hampers many species from tracking the spatial changes in their climate space, which potentially would require interventions supporting species dispersal.

The characteristics of the PAs themselves also affect species persistence. One basic principle is that smaller PAs are able to support smaller populations of species. Additionally, climate change may affect the strength of the density dependence regulating a population, and this can influence local populations in smaller PAs differently than in larger ones. Thus, the highly variable climate projected for future years may impede in a temporally varying population from returning to former population levels most strongly small PAs (Crick 2004), causing increased risk of local extinctions. However, new research is required to better understand the links between extreme weather events and population fluctuations and crashes, and particularly how well species with different traits are buffered against the environment-driven fluctuations.

Increased topographic and habitat heterogeneity within PAs will supposedly support higher species richness and also provide increased chances for local populations to survive due to the wider availability of different microclimates buffering the impacts of climatic variations (Thomas and Gillingham 2015). Moreover, topographically heterogeneous PAs may help species to avoid misusing phenological triggers and the associated temporal mismatches between trophic levels (Crick 2004). However, studies of this sort are in short supply for northern biomes. There is also a need to link such studies with the life histories of species to be able to recognise what types of bird species the environmentally variable PAs benefit the most. In addition, little is known about the extent of which environmentally diverse PAs offer sufficient long-term protection to bird species because the local temperature variations, even in topographically variable PAs, will usually not compensate for the projected increases in regional temperatures towards the end of this century (Ackerly et al. 2010). This again highlights the importance of the ability of species to migrate to new areas and PAs.

Conclusions

This paper shows evidence of climate change effects on northern European birds, underpinning the facts that species are shifting their ranges towards north with range sizes of many species declining and that these changes are different in northern and southern species and in species occupying different habitats. Importantly, species decline less within than outside PAs showing that protected areas alleviate climate change effects on bird species of conservation concern. This finding, further supported by results from elsewhere in Europe, provides evidence for the resilience of PA networks in preserving species under climate change. Representative PA network that includes high cover for key habitats is hence needed in all latitudinal zones. The projected efficiency of the PA network in maintaining biodiversity was partly dependent on the strength of climate change varying with respect to future scenarios. This suggests that a flexibly adaptive climate-wise conservation planning is required to be better prepared for preserving biodiversity in the face of uncertain climatic change.

The paper discusses several aspects of climate change studies and avian biodiversity that have been hitherto understudied especially in the northern biomes. We suggest that future studies should concentrate on (1) abundance-based models and prioritisations, (2) species' adaptive capacity (ability to avoid the impacts of climate change through dispersal and/or evolutionary change) and sensitivity (limited potential to persist in situ under changing climate) to climate change, (3) the role of the landscape matrix around the PAs and (4) the effects of the biogeophysical features of the PAs.

In conclusion, we envision that improved assessments regarding the ability of PA networks to maintain biodiversity in northern biomes, as well as the climate-wise conservation planning under climate change in general, require more in-depth examinations of the different risk sources, ranging from species exposure to climate change and their traits to the impacts of the biogeophysical features of PAs and land use on the matrix. Such cross-cutting analyses will help researchers distinguish between areas where the different climate change-based risks are low or moderate and areas where many climatically vulnerable species coincide with PAs with a lowered buffering potential and severely degraded matrix. Such maximal risk areas may require major restoration measures to increase their value in the PA network.

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Wild Power, Biodiversity and Solar Farms: A Business Model to Encourage Climate Change Mitigation and Adaptation at Scale

David Gazdag and Guy Parker

Abstract The UK is facing a sustained decline in biodiversity while struggling to meet its targets for renewable energy production. Wild Power is a new approach to renewable energy supply that requires native biodiversity to be restored on its generating sites as a core component of the business model. A customer pays a small premium which is used to encourage biodiversity, and in return receives a guarantee of renewable energy supply and biodiversity benefit. Solar farms are the ideal vehicle for delivering biodiversity benefits as the panels oversail the land, most of which is available for ecological enhancement. Furthermore, solar farms are spread across the landscape and collectively cover a significant land area. Core to Wild Power's approach is engaging local communities with solar farms to raise awareness of the multiple benefits of this technology, but also as a means of reconnecting people with nature. The Wild Power approach has been designed for UK solar farms, with aim to expand to wider renewable technologies, and countries in time. It is believed that this approach is novel and has global implications for biodiversity and sustainable development. This chapter presents the Wild Power model and describes its intent to encourage renewable energy as a means of mitigating climate change and promote adaptation through the creation of biodiversity-rich sites that should also enhance ecosystem services delivery.

D. Gazdag (✉)
Wild Power Ltd., Bank House, Southwick Square, Southwick, West Sussex BN42 4FN, UK
e-mail: david.gazdag@wildpower.org
URL: http://www.wildpower.org

G. Parker
Wychwood Biodiversity Limited, Damerells Combe, Aveton Gifford TQ74NQ, UK
e-mail: guy@wychwoodbiodiversity.co.uk

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The UK's Biodiversity Decline

Recent studies indicate that the UK's biodiversity decline is even greater than the global average (Hayhow et al. 2016). Between 2002 and 2013, it is estimated that 53% of UK species declined (Hayhow et al. 2016). This decline is attributed to agricultural practices as well as pressures from climate change. Habitat fragmentation through agricultural development appears to exacerbate biodiversity loss (Fahrig 2003). New evidence suggests climate change effects may be accelerated with the slowing of the Gulf Stream (Caesar et al. 2018). Clearly there is need for urgent mitigation of climate change and biodiversity loss.

Solar Farms and Climate Change Mitigation

Solar power has the ability to mitigate the effects of climate change. Solar photovoltaics are among the best ways to decarbonise the electricity production, being scalable and relatively easy to develop. A single 5 MW site saves around 2150 tons of CO_2 (STA 2018) as compared to UK baseline electricity generation per annum, which over the 25-years lifespan of a solar farm equates to a saving of around 54,000 tons.

Solar power has rapidly expanded in the UK since 2010, with large scale ground mounted solar being responsible for around 8.6 GW of energy generation today. There are more than 1200 utility scale solar farms spread across the UK (Fig. 1), covering an estimated 19,000 ha (Scurlock, NFU; pers. comm.). In combination, they significantly contribute to the UK's targets to reduce CO_2 generation by 80% in 2050.

Many solar farms were built on former arable land. When land is converted from arable production to permanent grassland (the typical land cover for a solar farm in the UK), it has the potential to switch from being a net producer of carbon (a carbon 'source') to a net receiver of carbon (a carbon 'sink'). Arable fields produce carbon through all the intensive inputs required to grow a crop, including chemical fertilisers, pesticides and machinery time. By contrast, permanent grassland requires few inputs and produces a thick mat of vegetation which is effective at storing carbon. While the overall reduction in CO_2 may be small (around 1 ton/ha or less than 1% of the reduction due to renewable energy production (POST 2015; FAO 2010) this effect can be significant at the national and global level and should contribute to the long-term Paris goals for negative emissions.

Fig. 1 Map of large scale solar deployment (planned and constructed) in the UK from April 2017 (*Source* BEIS Renewable Energy Planning Database, 2017)

Solar Farms and Climate Change Adaptation

Solar farms also have the ability to contribute to climate change adaptation, to counteract the changes to the environment caused by climate change. The likely effects of climate change upon the UK include increases in temperature, changes in the seasonality of rainfall, and an increased frequency of extreme events such as floods, with knock-on effects for the distribution and density of native biodiversity.

Where solar farms were constructed on former arable land, converting the land cover to permanent grassland should reduce the risk of flooding and erosion events by creating a stable, permanent and well-vegetated ground surface.

If traditional grasses or wild flowers (e.g. fine grasses and herbs) have been established, this form of vegetation tends to be more drought resistant than agricultural crops or pasture grasses, since wild flowers and fine grasses tend to have deeper roots. Such areas are more likely to resist single severe drought events or multiple small drought events.

Where solar farms are managed to encourage wildlife, they should provide refuge for a variety of native plants, invertebrates, reptiles and birds (Montag et al. 2015). A network of solar farms managed for wildlife spread across the landscape should support adaptation of wildlife to climate change which requires space and a variety of habitats in order to adapt to shifts in range.

Finally, sites that are rich in biodiversity are likely to provide a range of ecosystem services for the benefit of society. These services are likely to support agricultural production, as discussed later in this chapter.

Solar Farms and Biodiversity

The relationship between solar farms, land management and biodiversity has been the focus of recent studies and there exists a small but growing evidence base as well as a large body of independent research into parallel agri-environment schemes. Recent evidence suggests solar farms can provide positive benefits for biodiversity where creation of native habitats, including species rich grasslands, hedgerows and wetlands has been undertaken (Montag et al. 2015).

Biodiversity gains from such management approaches can include a higher diversity of botanical species, a higher abundance of common species of butterfly and bumblebee, and a higher diversity of breeding birds, including greater abundance of species of conservation concern (Montag et al. 2015).

The solar industry, in developing its approach to biodiversity, has borrowed land management options from the UK's agri-environment schemes (BRE 2014). Options such as grassland field margins and native species-rich hedgerows can fit well around solar infrastructure and have been recognised as priority habitats for the UK Biodiversity Action Plan (JNCC 2012). Field margins can harbour arable wild flowers such as shepherd's needle, corncockle, broadleaved spurge, cornflower, corn buttercup and pheasant's-eye which are rare in the wild. In turn, wild flowers are important sources of nectar and pollen for bumblebees, wasps and butterflies. Grasshoppers and beetles take cover in the grasses, along with many beneficial predators, such as spiders and ladybirds, which feed on crop pests like aphids (Wildlife Trusts 2018). Such invertebrate rich habitats provide foraging for birds and small mammals.

Adoption of biodiversity-focused land management is fairly limited within the solar industry at present. Wild Power's approach is to promote the adoption of agri-environment style options for land management, but also to encourage the creation of rare habitat types such as species rich limestone or acid grassland, which have declined greatly in the past century and which have resulted in associated species like the Adonis blue butterfly having been virtually extirpated from the UK.

Ecosystem Services

Society benefits from nature in a multitude of ways in the form of food production, the provisioning of clean drinking water, the decomposition of wastes, and the pollination of crops amongst many others. These benefits, termed ‘ecosystem services’ contribute to human wellbeing and economic wealth (Millenium Ecosystem Assessment 2005). Ecosystem services are all underpinned by biodiversity, which can be, depending on the definition, a regulator of ESs, a final ESs or a good (Mace et al. 2012)

Solar farms that encourage biodiversity have the potential to supply a range of ecosystem services, including carbon sequestration, water cycling, crop pest predation and pollination. Research on solar farms and ecosystem services is currently limited, but it is possible to draw upon wider research undertaken on UK agriculture.

The SPIES project—Solar Park Impacts on Ecosystem Services (Armstrong and White 2018) has collated evidence on ecosystem service benefits from a range of different land management options. Land managers can use this decision-support tool to assess the impacts of different management approaches on ecosystem services. The evidence is sourced from a database of scientific papers, mainly concerned with agri-environment schemes, including the habitat options already mentioned above.

The SPIES tool is being used by Wild Power as a mean of assessing the value of different land management options for ecosystem service provision. To give an example, SPIES determines that creating field margins should positively impact the following ecosystem services: climate regulation, pollination regulation, water quality and flood regulation—along with maintaining habitats and biodiversity. Planting and maintaining hedges should positively impact habitats for biodiversity, pollination regulation and pest and disease regulation.

SPIES also considers cultural ecosystem service values such as recreational and aesthetic interactions, which for Wild Power, and for the solar industry more generally, can be an important component of public acceptance of a project.

It is likely that ecosystem services generated on a solar farm would not only benefit the solar farm itself, but should also support agricultural production in the surrounding landscape. It is not currently possible to say to what degree birds and insects associated with a biodiverse solar farm may have a positive benefit as crop pest predators upon surrounding arable land. In addition, it is not possible to determine the influence of pollinators with increasing distance from a source habitat. However, independent research is under way to address these knowledge gaps. For example, a study launched in 2017 is investigating the potential for strips of wild flowers planted within arable crops to encourage crop pest predators and so reduce pesticide use (Guardian 2018).

Pollination

Pollination is among the best studied ecosystem service in the UK and is afforded more specific attention here. The majority of global, and European, biodiversity is made up of insects, but still relatively little is known about the distribution and abundance of most species, and even less about their dynamics and the threats they face (Potts et al. 2015). This lack of knowledge on the status and trends of the majority of Europe's species is of concern and is particularly important for species that play important functional roles, such as pollinators.

Wild pollinators in Europe are dominated by 2000 species, including bumblebees and solitary bees, hoverflies, butterfly, beetle and other fly species. Declines in wild bees and hoverflies have been clearly documented in the Netherlands and the UK where monitoring has taken place (Potts et al. 2015).

According to SPIES, maintaining wild flower/nectar seed meadows and hedgerows, connecting habitats, creating buffer zones/filed margins, ceasing pesticide/fertilizer use and grazing later in the year are all management steps that should enhance pollinators, and would be expected on a Wild Power solar farm.

Data gathered from systematic surveys of selected pollinators on a Wild Power pilot solar farm in the UK present an interesting case study (Parker, unpublished data). Bumblebee abundance in the 3 years following baseline (when the solar farm was constructed and wild flower habitats were introduced) is seen to increase significantly, with moderate increases in species richness too. Butterflies on the other hand exhibit large fluctuations, with an initial spike in abundance, followed by a decline to below baseline levels. Species richness of butterflies declines through the survey period (Fig. 3).

The graphics of bumblebees and butterflies raise some interesting questions on the interaction between pollinators, and what services can a Wild Power farm provide. According to Potts et al. (2015), bumblebees have more stable population in UK and Europe, while butterflies are more volatile and continue to decline. This background volatility in butterflies may contribute to the fluctuations displayed in Fig. 2.

Honeybees are encouraged on Wild Power solar farms, as community involvement is central to the proposal, and honey is a useful means of demonstrating the connection between solar energy and food production. However, recent studies suggest honey bees can potentially compete with wild pollinators (Barbir et al. 2015, 2016). Based on this evidence, and until further research is available, Wild Power will set conservative guidance for the number of hives per hectare that a solar farm can support. This is an example of how Wild Power is committed to using the best available evidence to inform its management decisions.

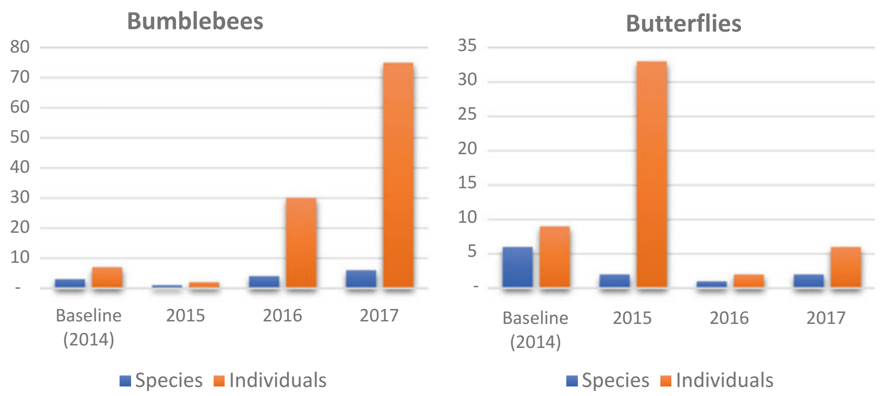

Fig. 2 Results of 4 years of invertebrate surveys at a single solar farm in the UK managed for biodiversity. Species richness is shown in blue and abundance is shown in orange (*Source* G Parker, unpublished data)

Scaling up

If all solar farms in the UK were managed for biodiversity, then their potential to deliver biodiversity and ecosystem service benefits could be significant at the national scale. However, only a small sub-set of solar farms currently adopt this approach. The question remains how to scale up these benefits across the solar industry. Wild Power aims to use market forces to ensure uptake at a meaningful scale for climate change resilience and adaptation, and UK's biodiversity and ecosystem services.

A New Way of Selling Electricity

While green electricity has growing demand, both in the corporate and domestic market segments, no supplier currently offers verified biodiversity benefits. Wild Power will sell renewable energy to domestic customers from sites that have been enhanced for biodiversity according to strict standards—and directly connects customers to their local sites. Market research indicates that a significant portion of buyers who are already committed to renewable energy will be willing to pay for this additional benefit. A scalable model has been designed to bring private financing for large scale biodiversity enhancement and climate change mitigation (Fig. 3).

Working with local ecologists, the rewilding plan is developed, based on the needs of the sites and in alignment with the rigorous Wild Power guidelines. The biodiversity outcomes are monitored annually using systematic methods and are subject to independent verification. Wild Power enters a contractual agreement with solar farms to purchase their future energy and provides them with the full package of re-wilding.

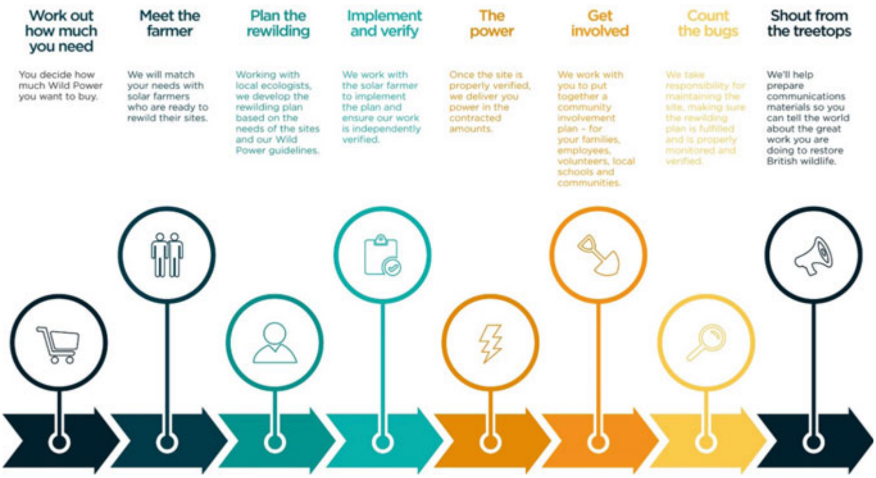

Fig. 3 The Wild Power process

As an integral part of the business model, Wild Power aims to engage customers and neighbouring communities in the solar farm's land management.

Wild Power Community Engagement

Wild Power aims to support climate change mitigation by encouraging acceptance of renewable energy production through its community programmes. Some community members may be concerned about visual impact on the landscape, or that the solar farm takes land out of agricultural production. By engaging community members in the activities of the solar farm itself (e.g. through site visits and monitoring activities) and by offering the opportunity to purchase power and thus contribute to wildlife management at their local site, it is hoped attitudes will be positively influenced.

European children fascinated by gadgets tend to spend less time playing outside. This results not only in the loss of connectivity with nature, but also with direct health problems (Moss 2012). Wild Power aims to use its unique offer to engage kids in a dynamic programme of education (both formal and informal) to demonstrate how a solar farm contributes to their life. For example, how their smart phones are charged, how a power plant works, how solar energy is transformed into the grid, how photosynthesis captures sunlight and how it is transformed through the food chain to the well-deserved lunch (Fig. 4).

Wild Power's approach to community engagement has been developed with the help of *Lorna Lyle, Director of Solar Power Education*. An example of activities is given in Table 1 below.

Fig. 4 Wild Power engaging with children

Table 1 Examples of Wild Power community and training programs

Activity	Description
Ecology Team Building and Bug Hotel Team Building	Community participants and customers work with ecologists to study and improve the biodiversity at a wild power site. They will learn 'on the job' about hedge planting, weed removal, seeding, building hibernacula and bug hotels, and undertaking botanical surveys
School Wild Power Car Challenge—Team Building	School children will design, construct, test and race solar or wind powered cars as part of a Wild Power challenge event
Educational Visits	School children will visit a Wild Power site and learn how renewable energy is generated, supporting their science learning and encouraging them to be thoughtful consumers. They will study the biodiversity of the site and follow this up with workshops in class. These activities are designed to fit into the National Curriculum
Teacher's Day	Teachers are invited to tour a Wild Power site, learn how energy is generated, complete a bug hunt and build a bug hotel, return to a local school to share findings and explore ways to use the site in the classroom

Wild Power is committed to sharing the results of its work both to raise awareness of biodiversity loss and climate change and to support practitioners in achieving best practice land management on solar farms. This will be achieved through education programs, collaboration with NGOs and universities, case studies published online sharing results through papers and symposia.

Sustainability

Sustainable development is at the core of Wild Power's business model. The 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development recognize that ending poverty must go hand-in-hand with strategies that build economic growth and addresses a range of social needs including education, health, social protection, and job opportunities, while tackling climate change and environmental protection (UN 2016).

Wild Power contributes to SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), SDG 15 (Life on land), SDG 7 (Affordable and clean energy) and is planning to expand to SDG 14 (Life Below water). Wild Power also aims to contribute to SDG 1 (No poverty) SDG 2 (Zero hunger) SDG 4 (Quality education) SDG 6 (Clean water and sanitation)—and in line with SDG 17 Wild Power seeks partnerships to reach our goals.

To scale up successful project cases to programmes or sustainable market level, it is important to adopt a holistic approach to private sector engagement on climate change and green growth (OECD 2018). As Wild Power extends its program to other renewable energy sources (e.g. wind, off-shore wind, hydro) and other countries and regions, the approach will be able to support multiple SDGs at a meaningful scale.

Conclusions

Wild Power encourages native biodiversity on solar farms as a core component of its business model. Wild Power sites have the potential to supply multiple benefits from the land, including the generation of renewable solar energy, improved biodiversity, and the supply of a range of ecosystem services including carbon sequestration, and water/air/soil quality, pollination, flood and soil erosion regulation, among many others. These benefits not only contribute to climate change mitigation, they also support adaptation both of native biodiversity and agricultural production. Such benefits are vitally important in the UK where land resources are limited and biodiversity is in decline, and are relevant to many situations globally.

Constraints of This Research

The Wild Power approach is constrained by the following knowledge gaps:

1. The evidence base concerning the relationship between solar farms and biodiversity is currently limited and further research is required to understand the positive and negative impacts of applying different land management options.

2. There is a limited understanding of the relationship between biodiversity and ecosystem services, and specifically the quantity and characteristics of ecosystem service supply from specific habitats.

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Handling the Impacts of Climate Change on Biodiversity

Walter Leal Filho

Abstract This final chapter describes the need for and outline some of the ways via which the impacts of climate change on biodiversity may be handled. It also suggests some measures which may be helpful in reaching different groups, so as to better engage them in adaptation efforts.

Introduction

Climate change and a whole and global warming in particular, are known to have a negative impact on biodiversity in three main ways. Firstly, climate change leads to increases in temperatures, which are known to be detrimental to a number of organisms, especially those in sensitive habitats such as coral reefs and rainforests. Secondly, the pressures posed by a changing climate may lead to sets of responses in areas as varied as phenology, range and physiology of living organisms, often leading to changes in life cycles (especially but not only in reproduction), losses in productivity or even death. On occasions, the very survival of some very sensitive species may be endangered. Thirdly, the impacts of climate change on biodiversity are estimated to be felt in the short term in respect of some species and ecosystems, but also in the medium and long term in many biomes. Indeed, if left unattended, some of these impacts may be irreversible.

The Convention on Biodiversity acknowledges the fact that biodiversity is affected by climate change, and that biodiversity, through the ecosystem services it supports, also makes an important contribution to both climate-change mitigation and adaptation. In addition, the Intergovernmental Panel on Climate Change (IPCC) has, in connection with its 5th Assessment Report (AR5), recognized the fact that without effective mitigation strategies, further changes in climate, atmospheric carbon diox-

W. Leal Filho (✉)
Faculty of Life Sciences, Research and Transfer Centre "Sustainable Development and Climate Change Management", Hamburg University of Applied Sciences, Ulmenliet 20, 21033 Hamburg, Germany
e-mail: walter.leal2@haw-hamburg.de

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Table 1 Some of the impacts of climate change on biodiversity

Impact	Environmental dimension	Social dimension	Economic dimension
Depletion of ecosystems	Damages to the structure of the physical environment	May lead to migration	Economical losses due to limited natural assets
Damages to specific species	Threats to the survival of sensitives ones	May lead to food insecurity	Income depletion
Disturbances in ecosystem services	Decreases in ecosystems´ productivity	May aggravate poverty	Losses in revenue from trade
Disruptions in life cycles	Changes in the dynamics of organisms and reproduction patterns	Limited availability of specific food stocks	Lower availability of resources, driving up prices
Changes in seasonal rythms	Distress to species	May cause social distress	May cause unemployment

Source Author

ide (CO_2), and ocean acidification may be expected. These are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity (IPCC 2014).

The current rates of biodiversity depletion which may be traced back to human activities are a reason for concern. Even though human activities have historically been seen as leading to losses of biodiversity, the intensity with which climate change as a whole and global warming in particular is taking place, means that a growth in the damages to natural assets and to the ecosystems services provided- some of which are crucial for human well-being- are expected. In particular, increased greenhouse gases emissions may be combined with other drivers such as extreme events (especially droughts) and accelerate biodiversity depletion. As outlined by Chapin et al. (1998) The ecosystem consequences of a changing biodiversity are significant and need to be avoided. But despite this reality, Leadley et al. (2014) outlined the fact that the degradation of biodiversity and ecosystem services over the twenty-first century could be far greater than was previously predicted.

The impacts of climate change on biodiversity may be seen at three levels: the environmental impacts, the social impacts and the economic impacts. Table 1 summarises them and offers an overview of their dimensions.

The list provided in Table 1 is by no means exhaustive. It serves the purpose of illustrating the variety of impacts seen, which indicate the need to adopt a preventive approach when trying to handle them.

One concrete case study can be seen at Lake Victoria, which is divided among Uganda, Kenya and Tanzania. With a surface area close to 27,000 mile^2, it is the biggest lake in Africa, and the second largest freshwater lake in the world, offering a basis for the livelihood of hundreds of thousands of people who depend on it for

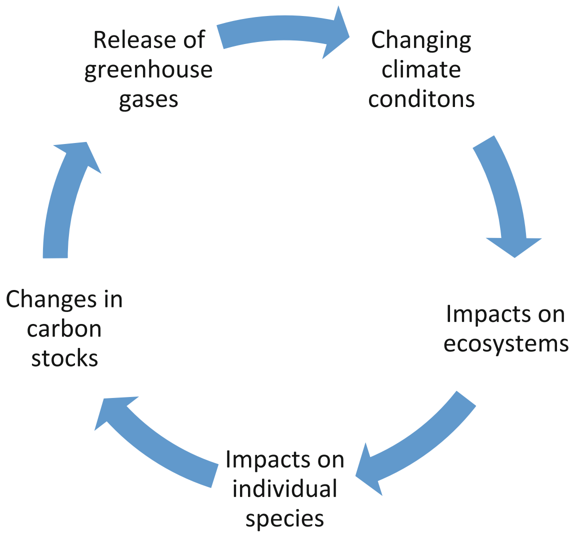

Fig. 1 Influences of climate change on biodiversity in the Amazon rainforests. *Source* Author

agriculture, fishing and other economic activities. As a result of climate change and the increased temperatures, levels of evaporation have increased. This is combined with the concentration of nutrients from agriculture on the water which, in turn, may provide good conditions for the excessive growth of algae or macrophytes, which seriously affect the water quality. These changes favour the most robust algal and animal species whilst the more sensitive ones may disappear, and the changes interfere with various beneficial uses of water (Gikuma-Njuru et al. 2015). The impacts of climate change to the biodiversity of Lake Victoria ersoty are well beyond the environmental ones: a reduction in the levels of fish production could lead to a imbalance in food availability. This could, in turn, aggravate poverty and possibly catalyse political instability in the affected areas.

A second concrete case study can be seen from the Amazon rainforests: climate change is believed to be influencing the dynamics of rivers in the region in a significant way. It may also influence their role as carbon stocks (Jantz et al. 2014) and the biodiversity elements it is associated with (Fig. 1).

In addition, increased temperatures and reduced rainfall in some areas may also reduce suitable habitat during dry, warm months and potentially lead to an increase in invasive, exotic species, which then can out-compete native ones. According to Brodie et al. (2012), there are many key concerns, among which is the fact that aridification could increase the accessibility of previously non-arable or remote lands, elevate fire impacts and exacerbate ecological effects of habitat disturbance.

As these two examples illustrate, the problem is serious and deserves prompt attention, despite the fact that there are some challenges which need to be overcome.

Challenges in Biodiversity Conservation Under a Changing Climate

There are various challenges which make the handling of the impacts of climate change to biodiversity a difficult task. Some of them are as follows:

i. climate impacts may affect ecosystems completely or in part, leading to changes in physio-chemical conditions and altering the structure of habitats;
ii. these impacts may also be felt as the species´ level, meaning that the most sensitive ones either considerably suffer or may even perish;
iii. damages to biodiversity are difficult to be reversed, especially when they are at advanced stages;
iv. apart from damages to fauna and flora, impacts on biodiversity often reflect on negative consequences to the livelihoods of some populations, especially the poorer ones which depend on natural resources as sources of income.

There are also many factors which exarcerbate the negative influences of climate change to biodiversity conservation. Firstly, the pressures caused by physio-chemical structures of some ecosystems, combined with a heavy reliance on them -and often their excessive use-, may lead to a decrease in their availability to provide their ecosystem services. This is the case of oceans at the macro level, which are shown to be influenced by climate change (especially, but not only by acidification), with various negative effects to the fauna and flora they host, or to lakes (which along with evaporation also are put under pressure by euthrophication) at the micro level.

Secondly, climate change affects biodiversity in the sense that it causes disruptions in food chains. The reductions in the population of some species—or the complete disappearance of particular species as the literature documents—may lead to changes in the food supply. For instance, reductions im plankton due to high temperatures may affect the many water based organisms which feed on them.

Thirdly, changes in temperature and weather conditions may trigger other phenomena which may seriously undermine biodiversity. The Intergovernmental Panel on Climate Change (IPCC) suggests that flooding associated with sea-level rise is likely to have substantial impacts on lowland areas such as the Amazon River delta (IPCC 2014). Another example is seen in respect of forest fires, as those observed in California or parts of Portugal and Spain in 2017. Long dry spells can provide suitable conditions for forest fires, which can spread over large distances and wipe out entire populations of animals and plants, over a short period of time.

There is also a perceived need to better communicate the connections between climate change and biodiversity (Leal Filho 2009; Leal Filho et al. 2018), since this may support attempts to catalyse real action.

At the macro level, the "Lima Declaration on Climate Change and Biodiversity" issued in 2014 lists a variety of measures which need to be pursued, to reduce the impacts of climate change on biodiversity. Since then, there have been calls for mutually supportive implementation of the nationally determined contributions under the Paris Agreement on Climate Change and the national biodiversity strategies and action plans under the Convention on Biological Diversity and its Strategic Plan for Biodiversity 2011–2020 (CBD 2017). It is important that coordinated efforts between the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity are implemented, in a way which is consistent with the action needed at the national and local levels.

Conclusions: Moving Towards Mitigating the Impacts of Climate Change on Biodiversity

At present, many individual governments, financial institutes and international donors are currently spending billions of dollars in projects around climate change and biodiversity, but with little coordination. Quite often, the emphasis is on adaptation efforts, with little emphasis on the connections between physio-ecological changes and the life cycles and metabolisms of fauna and flora, or the influence of poor governance on biodiversity.

There is therefore a perceived need to not only better understand the impacts of climate change on biodiversity, but also to engage on an action pyramid which entails a set of measures aimed at managing the many risks climate change poses to fauna, flora and micro organisms (Fig. 2). These are:

- identify the procedures which may be deployed to reduce the impacts of climate change to biodiversity
- test them with a view to checking their feasibility and efficiency
- implement them in a wider scale, with a replication and upscaling which may go well beyond the areas originally tested.

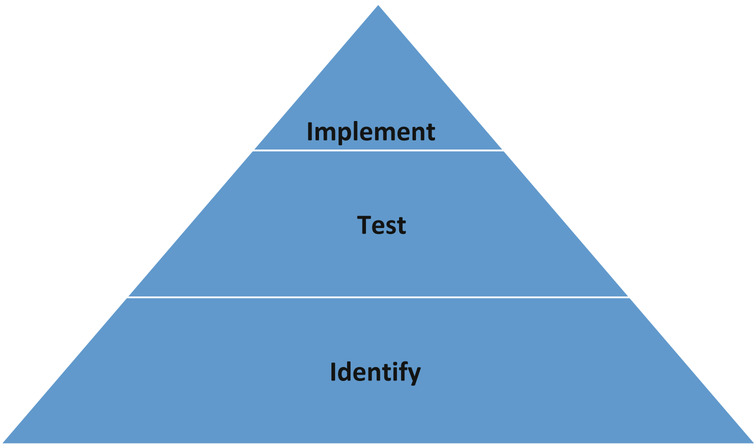

Fig. 2 Action pyramid to handle the impacts of climate change on biodiversity. *Source* Author

In particular, the question as to how better restore and protect ecosystems from the impact of climate change also has to be urgently addressed.

A second course of action needed, is a greater emphasis to the protection and/or restauration of the ecosystems most affected by climate change. Here, the list is quite long: from forests to lakes, from mountains to valleys and mangroves.

Ecosystem-based approaches to climate change adaptation should therefore be one of the top priorities, both in respect of government policies, but also in terms of development assistance. An investment in ecosystems protection is likely to yield benefits 10 times or more greater than the focus on a particular species. Efforts to protect and recover damaged ecosystems may potentially represent a significant step forward, since they automatically benefit the many plant and animal species, as well as microorganisms, which inhabit these ecosystems.

Furthermore, in trying to address the problems climate change poses to biodiversity, it is important to consider a set of the Sustainable Development Goals, especially:

- SDG 1 (No Hunger),
- SDG 2 (No Poverty),
- SDG 13 (Climate Action),
- SDG 14 (Life Below Water) and
- SDG 15 (Life on Land).

Since biodiversity issues permeate all these themes, an integrated approach is needed, as opposed to the many disconnected approaches which tend to prevail today.

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