CHAPTER

26

Biological diversity and climate change

Rik Leemans[1], *Sarahi Nunez*[1], *Rob Alkemade*[1, 2]

[1]Environmental Systems Analysis Group, Wageningen University and Research, Wageningen, The Netherlands; [2]PBL Netherlands Environmental Assessment Agency, The Hague, The Netherlands

1. Introduction

Climate change and other environmental changes are dramatically altering biodiversity (or biological diversity) patterns across the globe [1,2]. How biodiversity is expected to respond to these changes, was initially assessed emperically but is now also advanced by theoretical understanding. However, understanding these responses is crucial to better predict the composition, functioning, resistance, resilience, and recovery of biodiversity. Biodiversity is the variability among living organisms from all terrestrial, marine, and aquatic ecosystems and among all ecosystems and landscapes. Biodiversity thus includes diversity within species, between species and of ecosystems (Convention on Biological Diversity, UN-CBD). In this chapter, we will take a broad and generic perspective on terrestrial biodiversity, including species, communities, and ecosystems and their responses to climate change.

Internationally, many countries agreed in the UN CBD to conserve biodiversity, to sustainably use its components, and to fairly and equitably share its benefits. Also in the UN Framework Convention on Climate Change's objective (i.e., UN FCCC Article 2 [3], and Box 26.1) biodiversity and ecosystems provide important motives to limit climate change. This objective states, among others, that climate change should not jeopardize the natural adaptation of ecosystems and biodiversity. Ecosystems and their vulnerabilities probably also played an important role in defining the target of the Paris Agreement to maximally allow an increase in global mean temperature of well below 2°C above preindustrial temperatures, and, if possible, stay near 1.5°C. Though a safe level to protect biodiversity cannot be defined, beyond 2°C, the desired adaptive capacity of species and ecosystems is likely to be quickly limited [4].

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BOX 26.1

Article 2 of the UN Framework Convention on Climate Change.

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would **prevent dangerous anthropogenic interference** with the climate system. Such a level should be achieved within a time frame sufficient to **allow ecosystems to adapt naturally to climate change**, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner. (We emphasized the text.)

An additional essential argument to better understand the response of biodiversity and ecosystems is that all people strongly depend on them. The well-being of most human societies relies upon ecosystems and biodiversity that deliver, for example, food, fiber, drinkable water, carbon sequestration and climate mitigation, slope and soil protection, and beauty and inspiration. This delivery of these so-called ecosystem services, which resonate with the UN-CBD's sustainably use and equitable sharing, will also change under climate change and many will then be severely threatened [5].

However, climate change is not the only factor that threatens biodiversity, species, and ecosystems. Land use change and deforestation have altered and destroyed many ecosystems [6]. This has often led to severe habitat loss [7]. Exploitation has reduced biodiversity and altered ecosystems. It, for example, led to the collapse of marine and freshwater fisheries [8], and severe land degradation [9]. Pollution also negatively affected biodiversity in many regions. Often, the pollution source is far away from its effect (e.g., eutrophication of coastal areas by N and P supply through rivers [10]). Introduced novel species for a region could threaten the original species. If such alien species become invasive they often dominate ecosystems and alter their structure and functioning [11]. All these threats change biodiversity of many original communities and ecosystems locally and regionally.

People have tried to reverse this trend by conserving and protecting biodiversity and ecosystems through, for example, protected areas, ecological networks and programs to preserve endangered species. Currently, approximately 15% of terrestrial ecosystems are protected and 7% of marine ecosystems [12]. In the remaining (unprotected) land, sustainable management should maintain the desired levels of biodiversity, ecosystems, and their services. Additionally, reducing and minimizing all threats is urgently needed. This reduces pressures on biodiversity and ecosystems and allows them to better adapt naturally to climate change and the other threatening factors.

This short introduction shows that the link between biodiversity, species, and ecosystems and climate change is diverse and complex, and the other factors that affect biodiversity, species, and ecosystems should also be considered. But it also shows that people are concerned about biodiversity, species, and ecosystems and their services on which they depend. This concern partly drives policies to mitigate and adapt to climate change. In this chapter, we will discuss the many different (types of) impacts of climate change on biodiversity and ecosystems and try to put this discussion into the international climate policy context. We will focus mainly on terrestrial ecosystems. (Marine biodiversity is discussed by Worm and Lotze in Chapter 21.) We will especially assess the already observed changes in biodiversity and ecosystems and project how these changes continue into the near future (i.e., up to 2100). We will start with providing a short history of how impacts on biodiversity and ecosystems were assessed and quantified, followed by a review of the observed changes in biodiversity. Although such observed changes were traditionally just extrapolated into the future, we review the more comprehensive scenario-based modeling studies to assess the future impacts. Then, we will show how these future impacts are used to help motivate the target of the Paris Agreement and, finally, discuss if this target sufficiently limits the threats to biodiversity [13]. We conclude that the climate change threats to biodiversity and ecosystems are not easily mitigated.

2. A quick history of biodiversity impact assessments

Broecker [14] already in 1975 quantitatively predicted that the world's climate would become warmer. He introduced the term "global warming," which is still sometimes being used. Warming, unfortunately, ignores many aspects of climate change, such as changes in precipitation and extreme weather events. The first-ever study that assessed climate change impacts on the worldwide vegetation patterns only considered warming. Emanuel et al. [15] combined the Holdridge scheme to describe vegetation patterns with climate change scenarios. The higher temperatures made the planet drier resulting in less forests and much more deserts. They recognized that these results were unrealistic and corrected it by both using scenarios for temperature and precipitation change [16]. The resulting, more realistic results showed that over half of all vegetation patterns (e.g., forests) moved poleward, and areas with less future rains, grasslands, and deserts, expanded. The tundra, which borders the arctic seas, and alpine vegetation at mountain tops, were strongly reduced in their extent. This study was presented at Villach Climate-Change Conference in Austria, and this triggered Davis [17] to remark that these changes were much too large for species and ecosystems to adequately respond. These insights likely helped to draft the UN FCCC's objective.

Since these early climate change impact studies, many other studies quantified and further specified climate change impacts on biodiversity and ecosystems. Initially, simple vegetation climate classifications were used (e.g., Holdridge [16], Köppen [18], and Budyko [19]), but slowly new models that were better suited to deal with climate change emerged [20]. These more advanced models included responses to changes in seasonality, droughts, CO_2 concentrations, species dispersal, and sea level rise. Many confounding factors, such as land use change [20], further challenge species to track their preferred climate spaces across the often highly fragmented landscapes with many barriers, such as roads and other infrastructure, and agricultural fields. Also evolution and climate change was addressed as a way for species to adapt [21].

All the impact models used a baseline high-resolution climatology for current climate (initially the monthly data from the averaged climatic normal from 1961 to 1990 [22], which was later replaced by a monthly dataset covering all years from 1901 to 2000 [23]), that was overlaid with the coarser resolution climate change anomalies from the advanced climate models (i.e., the so-called general circulation models or GCMs) [24].

An influential synthesis of many impact studies was the assessment of worldwide extinction risk by Thomas et al. [25]. They convincingly showed that the medium climate-change scenarios would let a quart of all species be "committed to extinction" (or extinction debt), which indicates that species survive but not in a viable population or community. With an assumed effective species dispersal, the extinction debt was reduced to one-fifth. This study strongly stressed the urgency to implement climate mitigation measures. Urban [26] added a regional dimension to such extinction debt approach. He showed a similar magnitude of extinction risks but also reported that extinction risks will increase with higher levels of climate change. Extinction risks were highest in regions with many endemic species, such as South America, Australia, and New Zealand. Many studies have shown that extinction debts accelerate under increased climate change [27].

All these changes are well summarized in the seminal book by Lovejoy and Hannah on climate change and biodiversity [28]. This book was very timely at publication, but new insights and applications have surfaced in recent years. For example, comprehensive biodiversity indicators have been developed and used in impact assessments that cover many other threats to biodiversity than just climate change [29]. Results, however, depend on the actually selected measure to assess biodiversity responses, and this ultimately determines what aspects are to be communicated and emphasized. Also, many more impacts have been observed in all ecosystem and regions worldwide [30].

3. Observed changes in biodiversity

Observed changes were first included in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, www.ipcc.ch) [31], and this became the report's first conclusion: "Recent regional climate changes, particularly temperature increases, have already affected many physical and biological systems." A simple map showed that these changes occurred on all continents. IPCC's Fourth Assessment Report dedicated a specific chapter to observed changes [32]. The authors were highly confident (i.e., IPCC jargon) that physical and biological systems on all continents and in most oceans are already being affected by recent climate change, but that the attribution remained complicated because factors other than climate change affected these systems and because responses were not always direct and immediate. Most observations involved shifts in species ranges, phenology, local extinctions, productivity and C-sequestration, and changes in community composition. The latest IPCC report [33] carefully mapped all impacts and showed that new or stronger evidence now exists for substantial and wide-ranging impacts of climate change. Most changes occurred in the polar regions, mountain regions, and aquatic and marine systems.

One of the first observations stems from the Alps [34], where the treeline had moved upward. A later Dutch study came from an air pollution monitoring network with lichens, which have almost no dispersal limitations [35]. It showed that many lichens with a boreal preference had disappeared and many new lichens with a Mediterranean and even tropical preference appeared during the 1990s. Such shifts were later also observed for, for example, Dutch plant species [36], butterflies [37], and many other species [38]. These observations, however, did not limit themselves to species distributions [39]. Changes in the timing of biological events (i.e., phenology: leafing, flowering, etc.) could significantly be linked to climate change and weather variability [40,41]. All these observed changes were synthesized by Parmesan and Yohe [42], who demonstrated "with very high confidence" that climate change is already affecting species, ecosystems, and biodiversity.

The observations show that strong local differences exist between regions [42]. The polar regions show the largest changes in climate and the most sensitive terrestrial systems. Species extinctions have been observed in many regions. A quarter to half of all amphibian and bird species are vulnerable climate change [43], and up to one-tenth are already threatened with extinction, but these are very difficult to unambiguously link to changes in climate. A new analysis of observed impacts of climate change [44] indicates that climate change signals in terrestrial ecosystem are weaker than in marine ecosystems. Changes in land use and habitats, for example, are probably more important drivers of these terrestrial extinctions. Although some studies reported increases in local biodiversity [45], most regional and global studies indicate that biodiversity declines under climate change. The local studies focus on local alpha-diversity patterns (i.e., species richness) that are largely related to the introduction of exotic species (which maybe also benefit from climate change) or expansion of common species.

4. Future changes in biodiversity

The future of biodiversity is difficult to assess as it is determined by many, often interacting (including feedbacks) factors, time lags, synergies, and trade-offs. Species responses and ecosystems dynamics depend on the available species, their traits and histories, their communities, habitats and ecosystems in which they thrive, environmental properties, and environmental changes (including the timing of these changes). Many of these changes are driven by factors that are external to specific ecosystems (e.g., increased atmospheric CO_2 concentrations and changes in climate, weather, and land use), but others emerge from ecosystem processes, such as facilitation [46] and succession [47,48]. All these complexities are currently modeled to explore future changes in biodiversity. Since the earliest models [16], much progress has been made and many new insights emerged and old insights have become more precise and robust.

Climate change affects biodiversity as climatic factors (e.g., daily temperature range, moisture availability, and irradiation) largely determine the environmental conditions in a given area and thus the geographical distribution ranges, growth, and phenology of species. Biodiversity, species, and ecosystems already responded to past and contemporary changes in climate, and animal and plant species are expected to shift their ranges and appear in new locations or going locally and, in some undesirable cases, globally extinct.

Future biodiversity responses to climate change are generally based on different biodiversity modeling and climate change scenario approaches. One of the first predictive geographical models to project global natural vegetation patterns under future climate changes was developed by Prentice et al. [49]. Their BIOME model predicted the occurrence of a small number of plant types (i.e., deciduous and needle-leaved trees, shrubs, and grasses) in a given climate zone (wet and dry tropics, Mediterranean, temperate, boreal, and polar) using environmental data as temperature, precipitation, cloudiness, and soil classes. Contrary to the earlier models that simulated climate zones (e.g., Holdridge [16], Köppen [18], and Budyko [19]), BIOME created assemblages of different plant types, which could reassemble for past or future climates, shifting current biomes or creating new no-analog biomes.

Over the past decades, species distribution models (also known as species' climate envelopes, bioclimate envelope models, and environmental niche models) became one of the most widely used approaches to project future biodiversity (i.e., species) responses to changes in climate. This type of modeling correlates species geographical distribution ranges with climate variables, in some cases in combination with other environmental factors [50,51]. There exist numerous species distribution models that use different statistical techniques and can produce very different projections of species−range shifts [52,53]. Though the selection of a model depends on the overall goal of an impact assessment, a common practice is to use multiple statistical techniques and select the best (e.g., BIOMOD by Ref. [54]) or combine the different models in an ensemble [55] to reduce uncertainties and generate more robust results.

These models also spurred the development of dynamic global vegetation models, which simulate not only vegetation and species distributions and ecosystem dynamics but also the underlying carbon and nutrient processes that are important as drivers of CO_2 fluxes between ecosystems and the atmosphere. These models are now also better integrated in the advanced climate models, GCMs. Besides these dynamic models, the vegetation models also become more detailed by focusing on individual species [56] or group of species [52,55] and a stronger focus on specific regions [57]. Assessing the future of biodiversity should incorporate species distributions and interactions, demography and dispersal, environmental change, evolution, and species' phenology and physiology [58]. Models are now only starting to do so.

Scenario-based biodiversity modeling provides quantitative estimates of future changes in biodiversity as they explore the consequences of environmental change on biodiversity. These estimates typically result from the coupling of several approaches and methods, including species distribution models and scenarios for climate change, land use, and exploitation of ecosystem services [59]. Regional and global scenarios of changes in biodiversity have been developed for different time spans [60−62]. These scenarios consistently reported biodiversity losses over this century. However, they often assume a "no-dispersal" world or an immediate dispersal option. Frequently, species may adapt or disperse to some extent [63], but this is rarely considered. The scenario results could thus well overestimate the losses. Scenario-based modeling also contributes to appraise the effectiveness of biodiversity conservation measures and to inform decision-making aimed at safeguarding biodiversity [64]. Here, for example, this approach can inform future benefits and adverse effects of land-based mitigation options on biodiversity [65].

The latest scenario development involves the use of the so-called representative concentration pathways (RCPs) that define different levels of future climate change, and shared socioeconomic pathways (SSPs) that describe different socioeconomic conditions and their consequent emissions. Combinations of RCPs and SSPs span the plausible future scenario space, and these have already been used by the most recent IPCC climate change assessments

[64]. However, changes in future biodiversity are rarely assessed by combining RCPs and SSPs. Exceptions included Popp et al. [65], who for the first time developed a series comprehensive land use scenarios and determined the consequences of the different pathways for climate change mitigation by different land uses (improved agricultural and forestry management, bioenergy, or carbon sequestration). Each SSP showed different land use extents and patterns (SSP1 decreased the land use extent by over 700 Mha, while SSP3's extent increased by over 1050 Mha). They conclude that, generally, low agricultural demand and increased agricultural productivity and trade (i.e., SSP1) probably enhance the extent of natural ecosystems and thus biodiversity, but this was not explicitly calculated.

Schipper et al. [66] added this biodiversity step by using the GLOBIO model [67]. GLOBIO assesses the impacts of different biodiversity threats (climate change, N-deposition, land use, roads, and hunting) on the MSA index. When combined, this gives an overall biodiversity risk. Their result shows that biodiversity declines in all the SSP−RCP combinations but least in the "sustainability" (i.e., SSP1×RCP2.6) scenario and most in the "regional rivalry" (i.e., SSP3×RCP6.0) and "fossil fuel development" (i.e., SSP5×RCP8.5) scenarios. Large regional differences can be observed, however. In the "sustainability" scenario, impacts are largely benign (i.e., compared with current biodiversity levels!), and in some areas, biodiversity increases. This probably is caused by SSP1's decrease in land use and subsequent regeneration of nature. The "regional rivalry" and "fossil fuel development" scenarios show declines everywhere, but the largest declines, respectively, occur in tropical Africa or the Arctic. This seems directly to be caused by the different in climate change patterns and levels in the RCPs.

One of the most comprehensive and integrated biodiversity scenario studies was done for UNEP's project on The Economics of Ecosystems and Biodiversity (TEEB) [68]. This study assesses the historic (i.e., since 1700) human influence on biodiversity by using the mean species abundance (MSA) index, which is a simple multiplication of the percentages "species left" and "habitats left" in a region. MSA is one of the many biodiversity indicators listed by and used in the UN CBD. Under natural conditions, MSA would be 100%, but it decreased from 97% in 1700 to 90% in 1900 and 67% in 2000 (Fig. 26.1). The largest decline is thus in recent decades, and the main drivers of this decline were expansion of arable land, grazing land and land for biofuels, climate change, and nitrogen deposition and eutrophication. The study starts with current worldwide biodiversity patters (ignoring marine biodiversity but considering sustainable fisheries) and determines the effect of different conservation, agricultural, and climate change policies (Table 26.1). The conservation policies, for example, increase protected areas by 20% or up to 50%. This reduces the decline of biodiversity a little but not substantially, partly because factors, such as climate change, continue to execute their impacts. Reducing deforestation also affects the carbon flux to the atmosphere and slows the CO_2 buildup, thus mitigating climate change. Agricultural expansion has been a major driver of climate change, and currently, most available agricultural land is occupied (and often being degraded). However, agricultural productivity can easily increase in many regions, losses can be minimized, and fisheries can become much more sustainable. This reduces the further necessity to expand agricultural land. Additionally, shifting prosperous diets with much red meat to diets with less meat (flexitarians) or vegetarian diets reduces the demand for grazing land and crops for fodder. This slows deforestation, reduces methane emissions from ruminants, and thus helps to mitigate climate change. A vegetarian diet would half the amount of

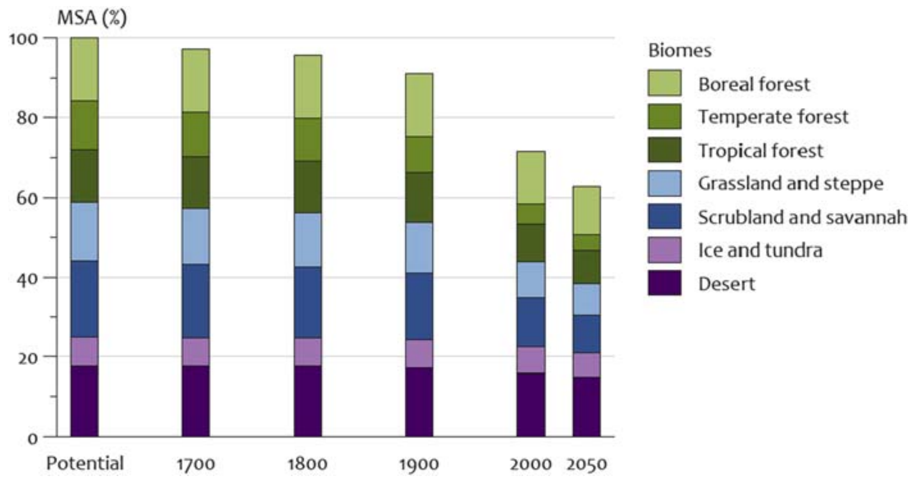

FIGURE 26.1 Change in the mean species abundance (MSA) index throughout the ages and for a baseline scenario without policy measures in the middle of this century [68].

TABLE 26.1 Integrated policy scenarios in The Netherlands Environmental Assessment Agency et al. for UNEP's TEEB project [68].

Priority setting in conservation		
1	Expanding protected areas	Conserving rare and valuable habitats, endemic species, hot spots, and a representative selection of ecoregions
2	Reducing deforestation	Maintaining carbon uptake and storage in forests; synergy with climate change mitigation
Reduced agricultural expansion and eutrophication		
3	Closing the yield gap	Increasing agricultural yields to reduce agricultural expansion
4	Reducing postharvest losses	… in the food chain, thus lowering agricultural production and reducing expansion of agricultural land
5	Changing diets	… to less meat consumption patterns, reducing the agricultural area for cattle feed and grazing
Reduce overexploitation of habitats		
6	Improving forest management	More forestry plantations with high productivity, and more reduced-impact logging outside plantations
7	Reducing marine fishing efforts	Bringing potential future marine catches to a higher, but sustainable level
Limit climate change		
8	Mitigating climate change	Reducing the impact of climate change with and without bioenergy to investigate trade-off from growing energy crops

current agricultural products used now [69]. Also improved forest management and limiting climate change has positive effects on biodiversity and climate change.

All these different managing options have some effect as some of the threats on biodiversity are diminished, but the effects differ per region and measure. No single measure protects biodiversity. When measures are combined, the results improve, but even with all measures together, the decline of biodiversity is still not stopped. This is due to increasing consumption of a more prosperous population worldwide. The study's main take-home message is that to halt the decline in biodiversity is almost impossible. Protecting valuable natural areas is important but insufficient. A clever strategy with all measures combined (i.e., including strict climate change mitigation) will slow the decline of biodiversity but also provides positive effects for food security, hunger, and climate change.

5. IPCC's reason for concern diagram

Biodiversity, species, and ecosystems have always played an important strong role in the discussions to set climate protection targets, as illustrated by UN FCCC's objective in Article 2 (Box 26.1). From early on, biodiversity and ecosystems were clearly sensitive and likely also vulnerable to climate change [70]. The difference between sensitivity and vulnerability is defined by, respectively, potential and actual impacts for a certain level of climate change (i.e., exposure). Potential impacts can be reduced or altered through adaptation, such as range shifts, phenological adjustments, growth responses, and evolutionary advances. Vulnerability is thus a function of exposure, sensitivity, and adaptive (human systems)[1] or coping (natural systems) capacities. Biodiversity, species, and ecosystems are thus more likely to be vulnerable to climate change than human systems.

UN FCCC's objective is to steer away from "dangerous anthropogenic interference" (Box 26.1). However, dangerous is not an easy-to-quantify scientific concept. What is dangerous from one person is excitement for another (e.g., bungy jumping). Defining dangerous levels thus involves political choices that can be informed scientific information on what most people find (un)desirable, (un)acceptable, or (in)tolerable (i.e., consensus finding). For its Third Assessment Report, IPCC was charged with providing such information. This daunting task resulted in a comprehensive synthesis of observed and future impacts of climate change [71] on (1) unique and threatened systems (i.e., biodiversity, species, and ecosystems); (2) extreme weather events; (3) the distribution of impacts; (4) aggregate impacts; and (5) large-scale singular events as a single value of "dangerousness" seemed impossible. These five so-called reasons for concern (RFCs) were assessed for different levels of climate change as indicated by a global mean annual temperature increase (Fig. 26.2). Such temperature increase is not ideal because biodiversity, species, and ecosystems respond to local and immediate changes in climate, but such temperature increase is easy to understand and to communicate, can be calculated by simple and advanced climate

[1]In the current climate change adaptation literature, adaptation is often a proactive adjustment to expected impacts to moderate harm or exploits beneficial opportunities. This is valid for many human systems, but natural systems only respond to actual changes in climate and their effects. However, human interventions can facilitate such responses.

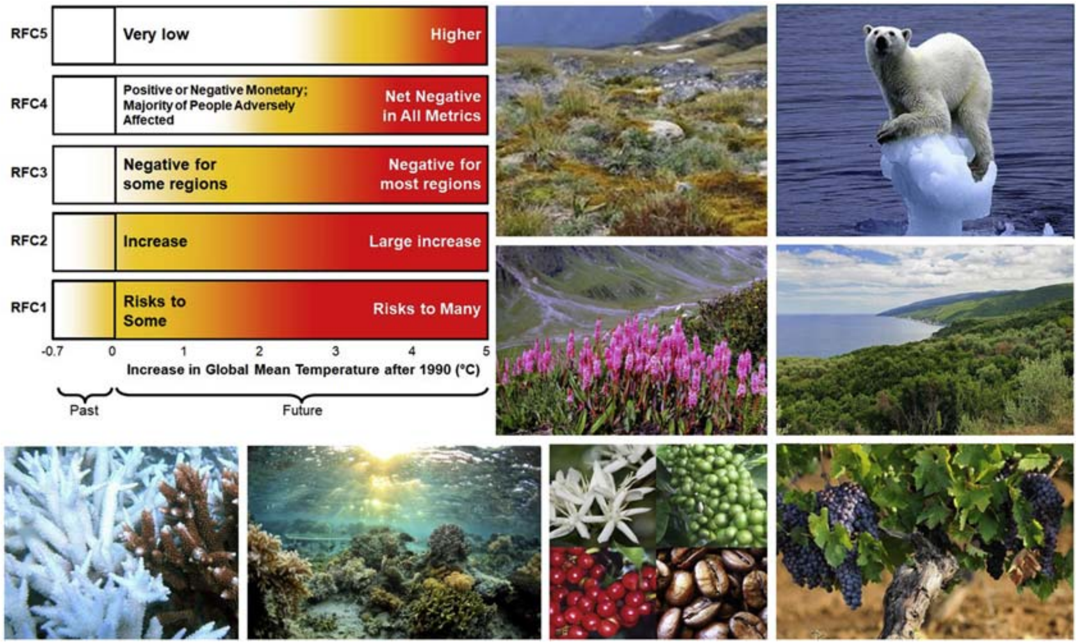

FIGURE 26.2 IPCC's "reason for concern" diagram and the impacts on biodiversity [71]. Note that the temperature scale differs from Fig. 26.3's scale. The zero-temperature line here is 1990, which is 1 higher than preindustrial temperatures depicted in Fig. 26.3 as zero temperature.

models, and resonates with policy makers and negotiators in the UN-FCCC. The next step was to indicate different levels of "dangerousness" or "risk." This was done visually by using a gradual color scale ranging from white (few risks), yellow (moderate risks) to red (large or dangerous risks). This resembles a traffic light apart for the color green (indicating safe and not few risks).

RFC I especially deals with biodiversity, species, and ecosystems. From observations and modeling studies, tropical coral reefs, tundras, and mountainous and coastal ecosystems are deemed most vulnerable. Coral reefs are threatened by CO_2-driven ocean acidification and temperature-driven bleaching. Experts (Chapters 12 and 21) believe that reefs will start to disappear at a warming of 1.5°C (and at the concurring changes in other climatic factors, such as precipitation, drought, radiation, and extreme weather). Tundras are vulnerable ecosystems in polar regions, where climate changes are much faster than in other parts of the world, and they cannot shift northward because of the polar seas. When these systems warm, shrubs will become more dominant, and this results in a positive climate change feedback due to increased albedos, and its permafrost will melt that could cause much wetter conditions and the release of large amounts of methane, another greenhouse gas. These changes in tundra gradually accelerate with increasing temperatures but also result in a serious tipping point [72] before a global mean temperature increase of 2°C is reached. Mountainous areas are vulnerable because of the diminishing extent of the alpine areas and the elevation of tree lines due to climate change. Coastal ecosystems are affected not only by climate change but also by sea level rise. Coping capacities differ for different ecosystems. Seagrass meadows, salt marshes, and estuaries are all vulnerable, but their vulnerabilities strongly depend on local conditions. Mangroves are generally seen as much less vulnerable to sea level rise and climate change [73] (c.f. Chapter 23).

RFC I also relates to individual species (Fig. 26.2). One of the iconic species that are affected by climate change are polar bears, which are a top predator and live and hunt for much of the summer season on the Arctic ice. As this ice melts and the ice extent and thickness is reduced, the polar bears' habitat will disappear. Nowadays, polar bears are therefore more often seen near villages, where they become a nuisance. This new behavior has led climate change deniers believe that polar bear populations prosper, but the contrary is true [74]. Internationally, polar bears are officially classified as vulnerable by the IUCN, meaning its population is decreasing. Also other species are vulnerable. These include insects, plants, and amphibians and all other species with narrow or endemic geographic ranges. Even some crops that have high cultural or food values, such as local varieties of wine grapes or Arabica coffee (which is highly sensitive to changes in humidity), are vulnerable, but their growers and breeders will probably support them to survive. An adaptation measure for Arabica coffee is, for example, growing them in the shade of trees or in agroforestry systems.

All the evidence on the different vulnerabilities was assembled in RFC I. Adverse impacts of climate change are being seen at a temperature increase of 1°C above preindustrial (i.e., 1880) temperatures (Fig. 26.2). Furthermore, moderate risks are already observed, and large or dangerous risks start just below 2°C. A similar color scheme emerged from RFC II "Extreme weather events" that already wreak havoc around the world. The other RFCs have not yet reached dangerous levels and can, under current levels of climate change, probably technically and economically be adapted to (with the understanding of the 2001 IPCC assessment). IPCC's RFC diagram (also nicknamed the Burning Embers [75]) clearly indicates that dangerous climate change starts around 2°C of warming and its updates in the Fifth Assessment Report, where all colors moved down the scale further supported this.

Over the past two decades, the vulnerability assessments of ecosystems and their biodiversity have showed that biodiversity, species, and ecosystems are more vulnerable that initially thought [33]. This is mainly based on observed changes and impacts. As a matter of fact, many impacts that were already projected by models and scenarios occur earlier. The model-based impact assessments thus are likely very conservative. These vulnerability assessments showed that somewhere between 1 and 2°C anthropogenic climate change would become dangerous because several ecosystems will no longer be able to "adapt naturally." Early and effective climate change mitigation avoids biodiversity loss [76]. This was also substantiated in IPCC's Fifth Assessment Report.

The approach is likely to have influenced the negotiations of the Paris Accords in December 2015, which resulted in the agreement to hold "the increase in the global average temperature to well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels, recognizing that this would significantly reduce the risks and impacts of climate change." Many countries, however, considered that a warming close to 2°C would not be safe. The implications of a warming of 1.5°C were poorly known at that time. IPCC was invited to assess the impacts of this warming and in terms of risks, ambition and feasibility, and the related emission scenarios. The resulting IPCC report was published late 2018 [73], and it concluded that staying close to

1.5 degrees was not impossible but very ambitious. Also impacts associated with 1.5°C were less than those associated with 2°C, especially for natural systems. Additionally, most countries and sectors would be able to adapt, and adaptation costs would be significantly lower at the 1.5°C temperature rise.

This IPCC report [73] also provided an update of the RFC diagram (Fig. 26.3) by adding an additional color (purple, irreversible risk, and limited possibilities to adapt), adding confidence levels for the color transitions and, most importantly readjusting the coloring on the basis of current understanding. An outcome of the updated RFCs is that for all of them, the color transitions (from white to yellow and yellow to red) clearly shifted downward, indicating larger vulnerabilities than those established in the original diagram. Dangerous levels of climate change already occur now in certain regions for RFCs I and II!

6. Are the Paris Accords effective to protect biodiversity?

IPCC's 1.5°C report [73] also added additional RFCs for many different terrestrial and marine ecosystems, societal sectors (fisheries, agriculture and tourism), regions (e.g., the Arctic), and specific extreme events (coastal flooding and heat waves). The most vulnerable ecosystems were those affected by coastal flooding and in the Arctic. Again, biodiversity, species, and ecosystems clearly showed that 1.5°C would be the desired target if they must "adapt naturally" (c.f. Box 26.1). These IPCC results help to put the emission gap mitigation discussions into a better and more realistic perspective. The current nationally promised emission reductions (the so-called NDCs) only reduce the projected business-as-usual warming to 3.5°C [77], and such a level is thus a major threat to biodiversity, species, and ecosystems and severely limits coping and adaptation in many sectors (including those that depend on ecosystem services, such as fisheries, agriculture, and tourism). For example, Foden

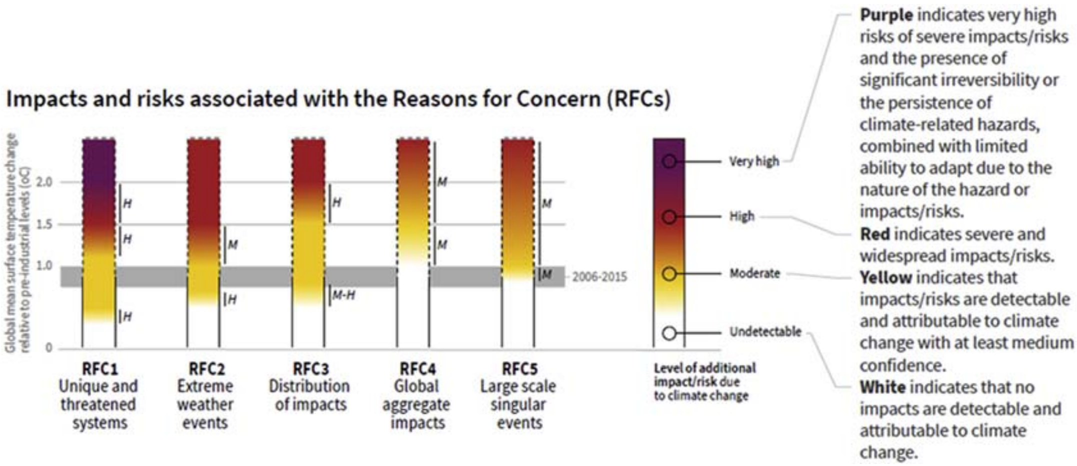

FIGURE 26.3 IPCC's updated "reasons for concern" diagram in its 1.5°C report [73]. Note that the additional color purple and confidence levels (*H*, high; *L*, low; and *M*, medium) to indicate how experts judge the legitimacy certainty of the color transitions.

et al. [78] recently estimated that such warming would increase extinction risks for one-third of all species within different species groups (i.e., corals, birds, and amphibians).

IPCC's 1.5°C report [73] assessed all the then available literature but did not engage in new studies. Several dedicated studies [79,80] have tried in different ways to determine if the Paris Target limits the impacts of climate change on biodiversity.

Smith at al [80]. examine how the risk to biodiversity differs between a warming of 1.5°C relative to 2°C based on direct impacts between different regions. They showed that the benefits for biodiversity of this difference are large. They, for example, calculated that at 2°C, a quarter of all plants would lose half of their climatic ranges, while at 1.5°C, this is reduced to only an estimated 10%. Benefits in certain regions are even larger. They also show that biodiversity conservation and restoration can help in mitigating climate change and even contribute to the probably necessary negative emissions that are required to reach the 1.5°C target.

Nunez et al. [79] did a systematic literature review of over 300 studies (but only 100 provided adequate data) on species shifts to estimate the magnitude of expected changes of biodiversity for plants, vertebrates, and all species combined under different global temperature increase levels toward the end of this century. They used simple but effective indicators to describe the shifts (i.e., the fraction of remaining species and the fraction of remaining area). These indicators were used to quantitatively compare many scenarios from different studies, and these fractions declined in all studies. They showed that local species richness and suitable climate area of many species were significantly reduced by 14% and 35%, respectively, between 1 and 2°C increase in global mean temperatures. Stronger declines were found beyond 3°C of temperature increase. They convincingly showed that even moderate levels of temperature increase will result in undesirable biodiversity loss.

Although the 1.5°C target shows climate change impacts on biodiversity, species, and ecosystems, with the impacts being much smaller than at higher levels of warming (and other climate and weather factors), the impacts are not zero. Many impacts are already occurring, and others will surprisingly emerge, and some will likely be irreversible. Adaptation will sometimes be possible, and this probably slows further reductions in local and regional biodiversity and stretch extinction debts in time. To counter these negative biodiversity trends, more effective emission reductions to keep warming near 1.5°C are urgently needed everywhere in the world, and these should be combined with supplementary conservation and restoration efforts, and measures to reduce other threats on biodiversity, species, and ecosystems, such as overexploitation, habitat destruction, and alien species introductions.

7. Conclusions

All the model-based studies are littered with uncertainties and probably do not give a fully correct picture on the future. Maybe, species are much more elastic, and under rapid environmental changes, evolution could well be accelerated [21]. Humans can help species to cope with climate change, protect their habitats, and restore their ecosystems by conservation efforts that simultaneously probably help to sequester carbon in ecosystems, such as peatlands and degraded forests. However, studies on earlier responses to (slower) past climatic changes resemble the modeled responses. At glacial maxima, for example, many tree species survived in southern refugia and migrated northward when icecaps and glaciers retreated again. The relatively poor species richness in European trees, compared with North America, is often explained by this oscillating migration process. In Europe, mountain ranges lie east–west, forming migration barriers, while in North America, they range from north to south, allowing migration. Such examples show that biodiversity, species, and ecosystems respond to climate change and that environmental conditions matter. This is robustly captured by models, and their results can be used to inform climate change mitigation and adaptation policies.

However, current landscapes are dominated by people's activities that probably limit present-day responses and provide additional threats to biodiversity, species, and ecosystems. Although climate change is rapidly becoming one of its major threats, the consequences of people's activities must be dealt with in an integrated and comprehensive way.

Many have argued that conservation efforts should focus on the biodiversity hot spots in the world [81], but that would possibly exclude some of the regions (e.g., the Arctic) that will be exposed to the largest climatic changes and high species and ecosystem vulnerabilities. An adequate conservation hot spot approach should thus also include the severity of each threat, including climate change. This demands a much more localized approach than the generic global approaches that are presented and discussed in this chapter. Additionally, interactions between threats, species traits, and ecosystem processes have to be considered together with effective local conservation efforts that facilitate the necessary biodiversity, species and ecosystems' responses [82].

Most people are now worried about climate change impacts and want to deal with this as local, regional, and global problems. People also care about and depend on biodiversity, species, and ecosystems. Unfortunately, this has not yet led to effective policies to halt the decline of biodiversity and limit climate change. The link between these two challenges is obvious as shown by our review. We showed in this chapter that strong climate change mitigation efforts are compellingly motivated by the unmitigated and observed climate change threats to biodiversity (and those of extreme weather events). Protecting biodiversity, species, and ecosystems, on the other hand, helps to sequester carbon from the atmosphere and increases resilience to cope with climate change. These two global problems are certainly interconnected in many ways.

Much research [77] shows that current pledges (i.e., NDCs) to reduce emissions are not enough and that much deeper emission cuts must be pursued to limit impacts and to allow for effective adaptation. Unfortunately, due to the 2020 COVID-19 crisis, many international negotiations and policy processes are postponed or delayed, and many governments are upholding their fossil fuel intensive industries, thus slowing down the required transitions. We hope that the urgency of dealing with those two problems returns soon on national and international agendas and that threats to biodiversity, species, and ecosystems are effectively dealt with and comply with the ambitious UN FCCC's and UN CBD's objectives.

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