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Climate change as a threat to biodiversity: An application of the DPSIR approach

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ABSTRACT

Climate change and its consequences present one of the most important threats to biodiversity and the functions of ecosystems. The stress on biodiversity is far beyond the levels imposed by the natural global climatic changes occurring in the recent evolutionary past. It includes temperature increases, shifts of climate zones, melting of snow and ice, sea level rise, droughts, floods, and other extreme weather events. Natural systems are vulnerable to such changes due to their limited adaptive capacity. Based on an analysis using the DPSIR framework, this paper discusses some of the important socio-economic driving forces of climate change, with a focus on energy use and transportation. The paper also analyses observed and potential changes of climate and the pressures they exert on biodiversity, the changes in biodiversity, the resulting impacts on ecosystem functions, and possible policy responses. The latter can be divided into mitigation and adaptation measures. Both strategies are needed, mitigation in order to stabilise the greenhouse gas concentrations in the atmosphere, and adaptation in order to adjust to changes that have already occurred or cannot be avoided. One mitigation option, increased biofuel production, which is also a response to oil depletion, would change land use patterns and increase human appropriation of net primary production of biomass, thereby threatening biodiversity. By considering the first order and second order impacts of climate change on biodiversity when developing policy measures, it will be possible to integrate ecosystem and biodiversity protection into decision-making processes.

1. Introduction

According to the Convention on Biological Diversity (CBD), biodiversity “includes all plants, animals, microorganisms, the ecosystems of which they are part, and the diversity within species, between species, and of ecosystems” (CBD, 2003, p. 1).

Human well-being and development strongly depend on biodiversity and ecosystem services (UNEP, 2007). A wide range of biological materials not only provides the resources we need for food, clothing and shelter, but also contributes to other elements of human well-being, such as health. These resources are being lost due to damage to ecosystems as a result of multiple and interacting pressures. Biodiversity is decreasing and ecosystem services are reduced (Millennium Ecosystem Assessment, 2005).

The most important pressures on biodiversity and ecosystem services are habitat change (such as land use changes, physical modification of rivers or water withdrawal from rivers, and loss of coral reefs), climate change, invasive species, overexploitation, and pollution. Driving forces behind those pressures are among others demographic, economic, socio-political, cultural, religious, scientific, and technological changes. Although biodiversity may also change due to natural causes, current change is dominated by the anthropogenic driving forces (Millennium Ecosystem Assessment, 2005).

Current climate change combined with other human developments is stressing biodiversity far beyond the changes caused by natural global climatic changes that occurred in the recent evolutionary past (IPCC, 2001; Steffen et al., 2004). From climate science we know about the different possible and far- reaching threats of anthropogenic climate change, including temperature increases, shift of climate zones, sea level rise, droughts, floods, and other extreme weather events (see for instance Latif, 2007; Kromp-Kolb and Formayer, 2005; Dow and Downing, 2006). These threats will potentially have wide-ranging effects on the natural environment as well as on human societies (see, for example, Millennium Ecosystem Assessment, 2005).

Natural systems are especially vulnerable to climate change because of their limited adaptive capacity[1] and some of these systems may undergo significant and irreversible damage. In this paper we aim to identify the links between climate change as one major threat to biodiversity and its underlying socio-economic driving forces as well as the resulting impacts on ecosystem goods and services and human

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[1] The adaptive capacity is the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Stronger adaptive capacity decreases the vulnerability (inability of a system to cope with adverse effects of a change) and herewith increases resilience (ability of a system to cope with adverse effects of a change; susceptibility to harm/stress) (UKCIP, 2004).

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responses. This analysis is based on existing literature about links between climate change and biodiversity and it considers these links within the framework of the adapted DPSIR (Drivers–Pressures–State–Impacts–Responses) framework used in the ALARM[2] project and in this special section. The intention is not to develop all elements of the framework completely, but to illustrate each of the elements with particular reference to the climate change implications for biodiversity. In this way, the usefulness of the framework for discussion of complex policy issues is illustrated. Other pressures on biodiversity are considered in other papers of this volume: loss of pollinators (Kuldna et al., 2009-this issue), biological invasions (Rodríguez-Labajos et al., 2009-this issue), use of GMOs (Binimelis et al., 2009-this issue), use of chemicals (Maxim, 2009-this issue).

In order to reduce the pressures on biodiversity stemming from climate change, (socio-economic) driving forces behind climate change have to be identified, influenced and reduced (Spangenberg, 2007). In this respect it is important to analyse driving forces of climate change as well as the pressure of climate change on biodiversity and the resulting impacts and possible responses. Based on this analysis policies and strategies could be developed to reduce the anthropogenic impacts on climate (and biodiversity) by modifying the trends in the underlying causes. This allows the integration of biodiversity protection into climate change policies, thus enhancing its political influence and improving the chances for effective political action to be taken.

In the following section we first describe the methodological framework developed by Maxim et al. (2009-this issue), which provides an adapted definition for the DPSIR categories (Section 2). Based on this framework Section 3 discuss all elements of the DPSIR framework in the context of climate change and biodiversity, where we focus on the socio-economic driving forces, the links between climate change and biodiversity and possible policy responses that might decrease or alternatively increase the threats to biodiversity. Section 4 provides some brief conclusions from this analysis.

2. The DPSIR approach

The DPSIR approach is discussed by Maxim et al. (2009-this issue). From that paper we take the following definitions:

Driving forces are changes in the social, economic and institutional systems (and/or their relationships) which are triggering, directly and indirectly, Pressures on biodiversity.

Pressures are consequences of human activities (i.e. release of chemicals, physical and biological agents, climate change, extraction and use of resources, patterns of land use, creation of invasion corridors) which have the potential to cause or contribute to adverse effects (impacts).

The state of biodiversity is the quantity of biological features (measured within species, between species and between ecosystems), of physical and chemical features of ecosystems, and/or of environmental functions, vulnerable to (a) pressure(s), in a certain area.

Impacts are changes in the environmental functions, affecting (negatively) the social, economic and environmental dimensions, and which are caused by changes in the State of the biodiversity.

A response is a policy action, initiated by institutions or groups (politicians, managers, consensus groups) which is directly or indirectly triggered by [the societal perception of] Impacts and which attempts to prevent, eliminate, compensate, reduce or adapt to them and their consequences.

In the following we apply this approach – based on the definitions above – to the issues of climate change (pressure) and biodiversity loss (state). The causal chain starting from driving forces down to impacts on human well-being and responses is demonstrated.

3. Climate change and biodiversity

3.1. Driving forces

Climate change is a pressure that leads to biodiversity change. This section explores some of the driving forces for climate change in order to illustrate this element of the DPSIR framework. Human economic activity is a major underlying cause of rapid changes in atmospheric composition (in particular emissions of greenhouse gases and aerosols) and changing land cover and land use. Socio-economic development, resulting behaviour, policies, actions and underlying ideologies and religious, cultural or political beliefs underlie driving forces of climate change.

Some socio-economic activities are directly linked to climate change. Underlying the causes of climate change are basic societal trends that can be influenced partly by policy, however only in the long term (see also Rodriguez-Labajos et al., 2009-this issue). These trends include demographic, economic, socio-political, scientific and technological, cultural and religious factors (CBD, 2003). They can be seen as the basic driving forces for any human-induced development in natural and socio-economic systems.

Energy use, transport practices, land use practices, trade and tourism strongly determine the magnitude of climate change as a pressure on biodiversity. In Europe, the use of energy is the most significant driving force for climate change: greenhouse gas (GHG) emissions result primarily from the combustion of fossil fuels (oil, coal, natural gas)[3] for energy use in the energy production, transport, industry and residential sectors. Rather than discussing all of these sectors, the focus here is on transport as an important energy-consuming sector.

Transport is responsible for 22% of greenhouse gas emissions in the EU15 (excluding international aviation and marine transport) (EEA, 2008a). Between 1990 and 2005 emissions from domestic transport increased by about 26%. Road transport is the biggest transport emission source (93% share) and emissions increased continuously both for passenger transport (increase of 27% between 1990 and 2004) and for freight transport (EEA, 2006). Energy use and carbon emissions from freight transport grew faster than in almost any sector between 1995 and 2005. The road freight segment had the greatest percentage increase (38%) (EEA, 2008a). CO_2 emissions from international aviation are growing fastest with an increase of 73% between 1990 and 2005 (EEA, 2008a).

The growth in transport's GHG emissions and energy use can be explained to a large extent by increasing transport volumes (EEA, 2006). The number of cars has tripled in the last 30 years, with an increase of 3 million cars each year. Although the level of car ownership is likely to stabilise in most countries of the EU15, this will not be the case in the new EU countries (European Commission, 2001).

Regarding goods transport, changes in the system of production are to a large extent responsible for transport growth. Road freight transport growth in the EU is projected to continue, resulting in an increase in energy demand of more than 15% between 2000 and 2020 (EEA, 2006). The transport situation is to a large extent the result of policies and measures over recent years that were focused on individual mobility and construction of infrastructure. This has led to higher mobility in the private as well as in the business sector and thus a strongly increasing number of (air) trips. More transport is also necessary due to a still increasing demand for goods and services globally, for example in agricultural products or raw materials. Maritime transport is responsible for 13% of the world's total transport GHG emissions at the present time (EEA, 2006). Projections estimate a growth of 35–45% in absolute levels between 2001 and 2020, based on expectations of continued growth in world trade (Eyring et al., 2005).

[2] For more about this 6th Framework EU project see www.alarmproject.net.

[3] Fossil fuels dominate the fuel mix with a share of 80% (UNEP, 2005).

In addition, lifestyle changes in recent decades have led to a higher demand for mobility. Even in highly industrialized countries car ownership is still seen as a “symbol of freedom”. Furthermore, in the last few decades the share of women in the labour market has been increasing in Europe. This has increased the need for mobility and flexibility, with the consequence that families often have at least two cars. Higher incomes and improved infrastructure have led to leisure travel becoming a significant contributor to the increased passenger travel volumes (EEA, 2006). Out-of-town shopping malls have also created increased transport demand.

The changes in transportation have led to an increase of GHG emissions and concentrations of these gases in the atmosphere, which are causing climate change. Furthermore, climate change (here considered as a pressure on biodiversity) is leading to changes in biodiversity, which have an impact on ecosystems functions.

3.2. Climate change as a pressure on biodiversity

Global climate change is taking place due to the increase in the atmospheric concentration of greenhouse gases (GHGs). The gases that contribute most to the anthropogenic greenhouse effect are carbon dioxide (CO_2)[4], methane (CH_4), nitrous oxide (N_2O), and fluorine compounds (SF_6, 2PFCs). Although most of these gases occur naturally in the atmosphere, their recent significant atmospheric accumulation is the result of human activities. The emissions of greenhouse gases have altered the composition of the Earth's atmosphere and this has changed the energy balance of the earth system, leading to warming at the earth's surface. These changes will also have an impact on future global climate (Steffen et al., 2004).

According to the IPCC Working Group 1 report (IPCC, 2007a) the global atmospheric carbon dioxide concentration has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. The global atmospheric concentration of methane has increased from a pre-industrial value of about 715 ppb to 1732 ppb in the early 1990s and was 1774 in 2005. The global atmospheric nitrous oxide concentration increased from a pre-industrial value of about 270 ppb to 319 ppb in 2005. The combined radiative forcing due to increases in carbon dioxide, methane and nitrous oxide is +2.3 [range of uncertainty: +2.07 to +2.53] Wm^{-2} and the rate of increase is very likely to have been unprecedented in more than 10,000 years.

The IPCC report (2007a) concludes that warming of the climate system is unequivocal. It is observed in increases of global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea-level. Furthermore, “most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations” (IPCC, 2007a). The observed climatic changes include: a globally averaged temperature increase between 1850–1899 and 2001–2005 of 0.76 °C [Range of uncertainty: 0.57 to 0.95 °C]; an increase of the average temperature of the ocean to depths of at least 300 m; widespread decreases in glaciers and ice caps; global average sea-level rise of 1.8 mm per year [Range of uncertainty 1.3 to 2.3 mm per year]; average Arctic temperatures increased at almost twice the global average rate during the past 100 years; annual average Arctic sea-ice extent shrank by 2.7 [2.1–3.3]% per decade; increased temperatures at the top of the permafrost layer by up to 3 °C since the 1980s; significant changes in precipitation amount in some regions; more intense and longer droughts over wider areas since the 1970s, particularly in the tropics and sub-tropics; the frequency of heavy precipitation events has increased over most land areas; and widespread changes in extreme temperatures over the last 50 years. As discussed below, these changes affect biodiversity.

In addition to changes in averages of temperature, precipitation or sea-level, anthropogenic climate change is also linked to changes in the frequency and intensity of extreme events, which can also affect biodiversity. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics (IPCC, 2007a). Long spells of drought contributed, for example, to forest fires in the Amazon basin, Indonesia and Central America in 1997–1998. In Indonesia alone, an estimated 45,600 km^2 of forest were destroyed (UNEP, 2007).

There is also evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970 and there are also suggestions of increased intense tropical cyclone activity in some other regions, but the data quality in these regions is not so high so the evidence is not conclusive (IPCC, 2007a). The frequency of heavy precipitation events has increased over most land areas and widespread changes in extreme temperatures have been observed over the last 50 years. Cold days, cold nights and frost have become less frequent, while hot days, hot nights and heat waves have become more frequent. All of these changes in extreme events can be expected to affect biodiversity.

Scenarios for temperature rise and other climate variables vary considerably, depending on the emissions scenarios but also on uncertainties in climate models. According to the Intergovernmental Panel on Climate Change (2007a) the globally averaged surface temperature could increase by 2.0–2.4 °C above pre-industrial levels by 2100, if emissions are stabilized before 2015. If emissions are not stabilized until after 2060, the temperature rise above pre-industrial levels would be 4.9–6.1 °C by 2100. Even if the concentrations of all greenhouse gases were kept constant at the levels observed at the beginning of the 21st century, a further warming of about 0.1 °C per decade is expected (IPCC, 2007a). About twice as much warming is expected if emissions are within the range of the IPCC scenarios. So at least over the next two decades, the IPCC scenarios suggest a warming rate that is at least twice as large as the estimated natural variability during the 20th century.

The scenarios also suggest that it is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent and it is likely that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation. These changes in extremes would affect biodiversity.

The projected sea level rise by 2090–2099, relative to levels between 1980 and 1999, is between 0.18 and 0.38 m for the scenario with low greenhouse gas emissions and 0.26–0.59 m for the scenario with highest emissions (IPCC, 2007a). Even a small sea-level rise can increase the risk of storm surges. Flooding of coastal areas will affect the biodiversity in these regions. Precipitation is expected to increase in high latitude and equatorial areas, decrease in the subtropics, but increase in heavy precipitation events.

A further indirect threat to biodiversity as a result of climate change is the increasing acidification of the oceans as a result of increasing atmospheric carbon dioxide concentrations. Projections based on IPCC scenarios give a reduction of the average global surface ocean pH of between 0.14 and 0.35 U over the 21st century, adding to the present decrease of 0.1 U since pre-industrial times (IPCC, 2007a). The impacts of ocean acidification are speculative, but could be profound, constraining or even preventing the growth of marine animals such as corals or plankton (UNEP, 2007).

Frei et al. (2006) have quantified the possible changes in exceptionally strong precipitation events over the next 100 years in Europe using regional climate model simulations and statistical analysis tools. The results show that Alpine regions and northern European locations above 45° latitude (including major cities such as London, Berlin, and Stockholm) are likely to have more frequent and intense extreme precipitation events during fall, winter, and

[4] CO_2 emissions account for approximately 82% of total greenhouse gas emissions in the EU and 95% of these are energy-related. The energy-related share of emissions has increased slightly from 79% in 1990 to 81% in 2002 and this share is expected to remain approximately constant over the period to 2010 (EEA, 2004).

springtime by the year 2100. In Scandinavia, for example, unusual strong events that are now supposed to happen once per century will occur every 20–40 years. Snow cover will contract, sea ice in both the Arctic and the Antarctic is projected to shrink; heat waves and heavy precipitation events will very likely become more frequent (IPCC, 2007a).

The changes discussed above are generally thought of as gradual incremental changes. For the arguments in this paper we have mostly used the IPCC results, but there are other sources of information. “Shock scenarios” can be used to examine which complex adaptation strategies might be needed and which consequences they might have (for shock scenarios in the ALARM project see Carter and Rounsevell (2004)). Examples for such climate change shocks are the collapse of the West-Antarctic ice sheet (see for instance Van der Sluijs and Turkenburg, 2006; Tol et al., 2006) or the shut-down of the thermohaline ocean circulation in the North Atlantic (see for instance Vellinga and Wood, 2002). A particular risk associated with climate change are so-called “tipping points” (see, for example, the discussion in EEA, 2008b) beyond which large and rapid changes in the behaviour of natural and socio-economic systems can occur. Some of these potential non-linear changes are related to positive feedbacks in the climate system (Jaeger, 2007). Going beyond “tipping points” in the climate system would have major consequences for biodiversity.

3.3. State of biodiversity and changes due to the pressure of climate change

The Convention on Biodiversity finds that “the current levels of human impact on biodiversity are unprecedented, affecting the planet as a whole, and causing large-scale loss of biodiversity” (CBD, 2003, p. 2). Many subsequent studies have documented changes of biodiversity as a result of climate change, most recently, for example, EEA (2008b). The Millennium Ecosystem Assessment (2005) points out that climate change may have been a contributing factor in the extinction of at least one species, the golden toad (Pounds et al., 1999). Present evidence also suggests strong and persistent effects of climate change on both plants and animals, evidenced by substantial changes to the phenology and distribution of many taxa (Parmesan and Yohe, 2003; Root et al., 2003). For example, there have been substantial advances in the dates of bird nesting, budburst and migrant arrivals across the Arctic and in this region both birds and butterflies have shown considerable northward range expansions (Parmesan et al., 1999; Walther et al., 2002). The Millennium Ecosystem Assessment (2005) points out that certain species or communities will be more prone to extinction than others. Vulnerable species often have one or more of the following features: limited climatic ranges, restricted habitat requirements, reduced mobility, or isolated or small populations.

Some of the observed changes of biodiversity attributed to climate change include examples in the Arctic, mountain ecosystems and coral reefs. In the Arctic, shorter periods of sea ice coverage are endangering the polar bear's habitat and existence by giving them less time to hunt. In 1960 the average weight of polar bears in western Hudson Bay, Canada, was 650 lb. In 2004, their average weight was only 507 lb. It is believed that the progressively earlier break-up of the Arctic sea ice is responsible for this change (CBD, 2007). Climate change has also been observed to have serious impacts on mountain ecosystems. For example, in the Alps, some plant species have been migrating upwards by one to four meters per decade and some plants previously only found on mountain tops have disappeared (CBD, 2007). Rising ocean temperatures have been cited as one of the causes of massive coral bleaching episodes (Buddemeier et al., 2004). Widespread coral bleaching was unknown before the 1980s and there is evidence that warming together with intense El Nino events have resulted in a dramatic increase since then. The largest coral bleaching event was in 1998 (Wilkinson, 2002).

Climate change is already affecting birds in a number of different ways (see, for example, http://www.birdlife.org/action/science/sowb/pressure/46.html and Birdlife International (2008)).

These include changes in distribution and population density. For example, in the UK breeding birds extended their ranges by 19 km on average between 1968 and 1988 in association with increasing temperatures. Behaviour and phenology changes are also observed with earlier nesting times, delayed migration to the South, and changes in the times of breeding and the size of eggs. A recent study of 122 terrestrial bird species concluded that since about 1985 climate change has influenced population trends across Europe and the impacts appear to be stronger over time; the populations of 92 species have declined as a result of climate change, while the populations of 30 species increased (Gregory et al., in press).

In tropical or sub-tropical regions, longer dry periods are a threat to the elephant population in sub-Saharan Africa (CBD, 2007). Some of the largest remaining areas where tigers occur are the mangrove forests of Asia. The projected rise of sea-level could lead to the disappearance of the tiger's habitat, threatening the survival of the species (CBD, 2007).

An important source of biodiversity that is being affected by climate change is soil biodiversity. EEA (2008b) points out that climate change alters the habitats of soil biota, which changes the diversity and structure of species and their abundance.

The synthesis volume of the IPCC Fourth Assessment Report summarises the observed impacts of climate change with the conclusion that there is very high confidence that recent warming is strongly affecting terrestrial biological systems, including the kinds of examples given above. Furthermore, the IPCC (2007c) points to the observations of changes in marine and freshwater biological systems due to the increasing temperature of the water as well as related changes in ice cover, salinity, oxygen levels and circulation.

Thuiller et al. (2005) conclude from their research within ALARM that many European plant species could become severely threatened under different climate change scenarios. They examined the threat for 1350 plants species for the period from 2051 to 2080 for the four main IPCC scenarios. Furthermore, it has been estimated that a 2 °C temperature increase poses a limit for ecosystems, beyond which they suffer severe damage and non-linear responses increase (Van der Sluijs and Turkenburg, 2006). Thomas et al. (2004) estimate that 15–37% of a sample of 1103 land plants and animals would eventually become extinct as a result of climate changes expected by 2050.

Potential changes of ecosystems and biodiversity due to climate change are (IPCC, 2002; CBD, 2003):

- Ecosystem boundaries can move due to changes in precipitation and temperature; some ecosystems are able to expand into new areas, while others diminish.
- Habitats of many species might move poleward from their current locations. If, when, where and how fast they migrate varies strongly among species. Species that live together in an ecosystem are unlikely to move together, thus the composition (biodiversity) of many ecosystems will change.
- A drought or disease can kill off a small population, which is unlikely to be replenished.
- The reproduction time of species will change the length of the growing season in some regions.
- Diseases might spread more easily and pests might reproduce faster.
- Sea-level rise threatens coastal wetlands (20% by 2080 according to IPCC (2002)), including salt marsh habitats and mangroves, as well as coral reefs, which are vulnerable and ecologically valuable areas. It could also increase coastal erosion and salinization of soil.
- Some ecosystems are very vulnerable to climate change and might thus respond fast. Among these are coral reefs, mangroves, high mountain ecosystems, and permafrost areas.

- Endemic mountain plant species are threatened by the upward migration of more competitive sub-alpine shrubs and tree species, to some extent because of climate change.
- Projected changes in European annual average temperature are outside the tolerance range of many mountain species. Projections suggest that these species would be replaced by more competitive shrub and tree species, leading to considerable loss of endemic species in mountain regions.
- The survival rate of most bird species is likely to improve further because of the projected rise in winter temperature. However, it is not yet possible to determine what impact this increasing survival will have on bird populations.

IPCC (2007c) finds that the resilience of many ecosystems is likely to be exceeded this century by the combination of climate change and associated disturbances, such as floods, droughts, wildfires, and insects, together with other global change pressures on biodiversity such as land use change. The IPCC notes that for increases in global temperature exceeding 1.5–2.5 °C major changes in ecosystem structure and function are projected to occur, with mainly negative consequences for biodiversity.

The combination of the projected climate change, land use change and spread of alien species might limit the migration capability of species and their ability to survive in fragmented habitats (CBD, 2003).

Certain drivers of climate change, in particular energy sources, can directly change the state of ecosystems. This is well described in the 4th Global Environmental Outlook of UNEP (2007, chapter on biodiversity). For instance, oil spills have enormous impacts on aquatic and marine ecosystems, the use of biomass leads to the monoculture of fuel plants which increase soil and water pollution from fertilizer and pesticide use, soil erosion and water run-off with subsequent loss of biodiversity, or building large dams for water power plants leads to loss of forests, habitat and species populations.

3.4. Impacts of ecosystem and biodiversity change

Functions, goods and services of ecosystems are strongly connected to the biodiversity of these systems and are a basis for human survival and well-being (for a description of these goods and services see, for example, Millennium Ecosystem Assessment (2005)). These ecosystem functions are divided into supporting, provisioning, regulation and cultural functions (Millennium Ecosystem Assessment, 2005).

If species are lost or migrate to other areas they cannot provide food, water, fuelwood, fiber, biochemicals or genetic resources any longer, or only to a limited extent, although the ecosystem as a whole could continue to function. Climate change influences the climate regulation function of an ecosystem directly, but also indirectly via the change of the land cover and plants in a given area. An important regulating function of ecosystems is the uptake of carbon dioxide. Over the course of this century, it is estimated that net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or reverse, thus amplifying climate change (IPCC, 2007a). The climate regulation function of forests is another example of a service threatened by climate change. Forests have a higher evapotranspiration than other ecosystems, such as grasslands. Thus forests have a moistening effect on the atmosphere and become a moisture source for downwind ecosystems (Millennium Ecosystem Assessment, 2005). The decline of forests, such as the Amazon forest, as a result of changed precipitation patterns will severely affect this regulating service. Other regulating services, such as the regulation of disease, are also influenced and altered by climate change and by the change of land cover and plant composition. For example, warming and increased precipitation support the spread of disease vectors such as the mosquito.

Cultural services of ecosystems are strongly connected to the species living in such ecosystems. If they are lost or changed, such services cannot be offered any longer or are provided in another way, which might but need not always lead to a reduction of human well-being. The recreational service of coral ecosystems is a good example of an ecosystem service that is threatened by climate change. Increases in sea-surface temperature of about 1–3 °C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatization by corals (IPCC, 2007b).

Supporting services such as soil formation and nutrient cycling are changed if species are lost and if regulating services are changed. The net primary productivity of some species will increase due to a higher concentration of CO_2. The Millennium Ecosystem Assessment (2005) also suggests that if multiple dimensions of biodiversity are driven to very low levels, both the level and stability of supportive services may decrease.

Changes of ecosystems' functions and losses of biodiversity due to the pressure of climate change can themselves affect the regional and global climate, for example through changes of uptake and release of greenhouse gases; these feedbacks can be negative or positive (CBD, 2003).

3.5. Responses

This paper focuses on the pressure of climate change on biodiversity. This section therefore focuses on responses related to the pressure of climate change.

Since greenhouse gases have long residence times in the atmosphere, the earth will be affected for many decades or even centuries by the atmospheric burden that humans are creating today. This is especially true for so-called long-lived greenhouse gases (i.e. CO_2, N_2O, PFCs, SF_6; CO_2 has an atmospheric life time of up to 200 years or CF_4 more than 50,000 years). For several centuries after the CO_2 emissions occur, about one quarter of the increase in CO_2 concentrations caused by these emissions is still present in the atmosphere (IPCC, 2001). Model experiments show that even if all greenhouse gas concentrations were held constant at the levels of the year 2000, a further warming trend would occur in the next two decades at a rate of about 0.1 °C per decade, due mainly to the slow response of the oceans (IPCC, 2007a).

Because the oceans respond more slowly to global warming than the atmosphere does, the thermal expansion of the oceans, a major cause for sea-level rise, would continue for many centuries after the atmospheric concentrations of greenhouse gases were stabilized. For example, IPCC (2007a) shows that if radiative forcing were stabilized in 2100 at the levels of the A1B scenario (one of the SRES emission scenarios[5]), thermal expansion alone would lead to 0.3 to 0.8 m of sea-level rise by 2300 compared with the level in 1980–1999. The thermal expansion would continue for many centuries due to the time required to transport heat into the deep ocean.

There are basically two main strategies for tackling the issue of climate change: mitigation of greenhouse gases and adaptation to impacts. Both of them are addressed in the following.

[5] SRES is the Special report on emissions scenarios published by the IPCC. In 1992 the IPCC released for the first time emission scenarios to be used for driving global circulation models to develop climate change scenarios. These scenarios were path breaking. They were the first global scenarios to provide estimates for the full suite of greenhouse gases. In 1996 the next generation of SRES scenarios was released. The new scenarios also provide input for evaluating climatic and environmental consequences of future greenhouse gas emissions and for assessing alternative mitigation and adaptation strategies. They include improved emission baselines and latest information on economic restructuring throughout the world, examine different rates and trends in technological change and expand the range of different economic-development pathways, including narrowing of the income gap between developed and developing countries. The scenarios were used as input fort he 3rd and 4th IPCC assessment reports. See for instance: http://www.grida.no/climate/ipcc/emission.

Mitigation is the "anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2002, p. 69). Any reduction of greenhouse gas emissions contributes to a mitigation or at least deceleration of climate change, which reduces threats and pressures on humans and non-humans. Adaptation is the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities", (IPCC, 2002, p. 62).

These strategies can be seen as complementary. On the one hand, even if emissions are reduced to allow the achievement of a stable level of atmospheric GHG concentration, as indicated above, adaptation would be necessary due to the fact that the impacts of increased GHG concentrations on climate and ecosystem functions occur with an extreme time lag. On the other hand, adaptation alone would not be sufficient for ecosystems to further evolve or stay resilient. There are limits to the adaptive capacity of ecosystems and of social systems to new states such as increased temperature or reduced precipitation (on resilience, adaptation and adaptive capacity, see for example Adger, 2000; Berkes and Folke, 1998; Brooks, 2003; Brooks et al., 2005; Gallopin, 2006; Smit and Wandel, 2006). These considerations introduce an important time dimension into the discussion of adaptation and mitigation strategies. If action is taken within the next 8 years to reduce greenhouse gas emissions significantly, drastic climate changes can be avoided (IPCC, 2007a). For example, the IPCC (2007a) calculates that a stabilization of atmospheric greenhouse gases at the levels of the year 2000 would lead to a global temperature increase of 0.3–0.9 °C at the end of the present century, while a high emissions scenario shows temperature increases of 2.4–6.4 °C during the same time period. The stabilization would strongly reduce the need for adaptation but not eliminate it.

Mitigation activities influence biodiversity. Depending on the design and implementation of those strategies, their temporal and spatial scale and the ecosystem in question, they can have positive, neutral or negative impacts (UNEP, 2007). Examples of such strategies are provided by IPCC (2000) and include land use, land use change and forestry activities (LULUCF) such as afforestation, reforestation and land management practices, as well as the use of renewable energy sources (biomass, wind power, solar power etc.) instead of fossil fuels. Some of these strategies may lead to loss of biodiversity, for instance by substituting rapidly growing tree plantations for diversified forests in order to increase carbon uptake, or by growing biofuel crops (see also UNEP, 2007).

Other mitigation activities, leading to the reduction of fossil fuel use or activities using fossil fuels or enhancing sequestration by sinks, are taxes on emissions, carbon and/or energy subsidies favouring renewable energy sources, (non-)tradable permits, regulations and laws restricting the use of fossil fuels, voluntary agreements, technology and performance standards, support of energy efficiency improvement, road pricing, etc. (see IPCC, 2001; Working Group III Mitigation and IPCC, 2007b). Their impact on biodiversity is rather indirect via a reduced or mitigated climate change.

The reduction of GHG emissions not only has effects on biodiversity but could also have various impacts on the economy, as briefly explained here using the example of renewable energy. Despite the well-known positive economic effects of an increased use of renewable energies (e.g. the creation of additional jobs, the reduction of dependency on fossil fuels, etc.) and their potential to reduce GHG emissions there may also be some negative impacts on the economy. An abrupt switch to an energy system depending mainly on renewable energy sources would lead to severe problems in many economic sectors (e.g. high investments, missing or low potentials for expanding renewables, problems of electricity storage, alternative usages of crops like food or wood), but also for individuals (heating, mobility). Thus, some authors argue that the energy systems can only be changed over several decades and therefore suggest reducing the emissions of GHG by up to 4% per year (Van der Sluijs and Turkenburg, 2006). The switch to renewable energy technologies is of course strongly dependent on the potential given in a country. Austria or Switzerland, for example, are countries with a high proportion of rivers and a high share of biomass and can thus more easily produce energy from hydropower than other European countries. This has to be considered when requiring certain shares of renewable energy. Besides switching to renewables, incentives to increase energy efficiency and saving play an important role in responses to climate change. Although in recent years adaptation to climate change was an important topic on the agenda of the United Nations Framework Convention on Climate Change (UNFCCC) and IPCC and a lot of literature has been devoted to this issue, the discussion about adaptation and concrete policy measures is lagging behind that about mitigation (Levina and Tirpak, 2006).[6] Annex I member countries of the UNFCCC[7] are required to report about their mitigation and adaptation activities on a regular basis. These reports show clearly that adaptation is not seen to be as relevant as mitigation and only a few countries worldwide report on actual implementation of adaptation measures. Measures are mainly taken or planned in coastal zone management because of the threat of a sea level rise, natural hazards management (due to avalanches, floods, landslides), water resource management, flood defence planning, land-use planning, agriculture, health, protection of areas affected by floods, drought, and desertification (Gagnon-Lebron and Agrawala, 2006). However, no country has a comprehensive approach to implement adaptation in policies and projects.

Mitigation is able to reduce impacts on all systems, while adaptation is targeted at selected systems. As the results of adaptation policies can also depend strongly on local socio-economic and institutional contexts, the effectiveness of adaptation measures is less certain than that of mitigating GHG by for instance using less fossil fuels, which directly reduces the causes or driving forces of climate change. The success of adaptation measures is not directly measurable and difficult to evaluate, because effects often cannot be related to specific measures.

In developing countries adaptation is often regarded as priority, as a large proportion of their population is dependent on resources that are climate sensitive and as their adaptive capacity is lower. The potential for adaptation or adaptive capacity of human-environment systems is dependent on various factors (Toman and Bierbaum, 1996):

- the level of understanding of processes in these systems and options for preserving the flows of services provided by them;
- the diffusion of this knowledge among the affected decision makers and stakeholders;
- the financial and human resources available for adaptation measures.

The potential is quite large in countries with high levels of capital, stores of human knowledge, high levels of technology, good infrastructure and social institutions available for adaptation efforts. Activities that enhance the capacity are often the same as those promoting sustainable development (IPCC, 2001).

According to the definition, adaptation involves adjustments in systems as a response to impacts of climate change. These adjustments can be changes in processes, practices or structures to reduce the damages or to benefit from opportunities (IPCC, 2001). Different forms of adaptation can be distinguished, e.g. (1) autonomous adaptation of human and natural systems, which are usually not sufficient to counteract all negative impacts of climate change,

[6] At COP 11 (2005) a five-year programme of work on impacts, vulnerability and adaptation to climate change was adopted. It should assist the UNFCCC in making decisions on adaptation measures.

[7] Annex I Parties of the UNFCCC include the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States (http://unfccc.int/parties_and_observers/items/2704.php).

especially in the case of extreme weather events; and (2) planned adaptation (either reactive or anticipatory), which is costly and still leaves damages.

Adaptation aims at moderating the adverse effects of climate change through a set of actions. The general term adaptation has to be qualified for specific cases by specifying who or what adapts to which stimulus and in which process or form (IPCC, 2001). A package of different measures is more effective than a single measure (Levina and Tirpak, 2006). The objectives of adaptation policies should be embedded in the overall objectives of a nation/region.

Adaptation measures can have positive (e.g., adaptation of agriculture by using more crop varieties) or negative (e.g., building of dams that can dissect landscapes or submerge ecosystems) impacts on biodiversity. Measures, such as maintaining and restoring native ecosystems, protecting and enhancing ecosystem services, establishing nature reserves, integrated land and water management activities, and paying attention to traditional knowledge, are likely to have positive effects. The introduction of new species or certain management practices is likely to have negative impacts with various levels of severity (see, for example, Rodriguez-Labajos et al., 2009-this issue). Measures that increase the species-richness or genetic diversity of ecosystems can be important as they can lead to an increase of the potential to adapt to climate change (CBD, 2003; IPCC, 2002) and thus increase the adaptive capacity of a system. However, the advantages of such measures can be outweighed by the introduction of invasive species. There are opportunities for adaptation in agriculture and forestry that could, however, be costly (IPCC, 2001).

Recently, in other countries, such as Ecuador and Nigeria, a form of mitigation with positive impacts on biodiversity initiated by civil society is heavily discussed. One can distinguish two activities here: leave oil or coal in the ground to prevent CO_2 emissions and also to preserve biodiversity and avoid deforestation, which increases the CO_2 uptake and thus decreases its concentration in the atmosphere and maintains ecosystems and their functions. For both options payments should be provided.

An example is the ITT Yasuni proposal, in Ecuador. This proposal was developed by the civil society. The idea, first expressed in the Oilwatch position paper in Kyoto in 1997, is to keep fossil fuels in the ground and thus to receive carbon credits. In the ITT oil field in the Yasuni national park, about 920 million barrels of heavy oil would remain in the ground in perpetuity or in a moratorium *sine die*. This maintains an area that is inhabited by indigenous groups and that is rich in unique biodiversity. The avoided emissions of CO_2 are on the order of 410 million tonnes from the oil, plus some more from the avoided gas flaring and avoided deforestation. Keeping the oil in the ground and thus not profiting from this resource financially would mitigate climate change and reduce the biodiversity loss. For this, Ecuador is asking for monetary compensation (Martinez-Alier and Temper, 2007).

Synergies exist between mitigating climate change, adapting to climate change and enhancing conservation of biodiversity (CBD, 2003) and these synergies can be seen as an opportunity to implement mutually beneficial activities in response to climate change and loss of biodiversity. For example, setting up a biological corridor, which is a measure to conserve biodiversity, can also increase the uptake of CO_2 by the new plants.

With its “European Climate Change Programme II: Impacts and Adaptation”[8] (launched in October 2005) the European Union has already recognized that Europe must adapt to the climate change impacts that are already inevitable (see above) in addition to avoiding and reversing climate change through mitigation. However, so far, climate change considerations were not integrated into key EU environmental policies, such as the EU Biodiversity Strategy, the Habitats Directive and the Water Framework Directive, to any great extent (EEA, 2005). On the other hand, European policies on increasing the biofuel content in transportation fuels are geared to reducing CO_2 emissions (and subsidizing farmers) but they present a risk for biodiversity (either in Europe or in exporting countries).

The impacts of biofuels on biodiversity have been discussed by Russi (2007, 2008). The new European energy strategy, presented on 10th January 2007, says that biofuels should represent at least 10% of the energy used for transport. The main argument behind the policies in favour of biofuels is that biofuels would not increase the concentration of greenhouse gases in the atmosphere. In fact, the amount of carbon dioxide emitted by biodiesel in the combustion phase is the same as that absorbed by the plant during its growth. However, a more careful analysis of the life cycle of biodiesel reveals that the energy (and CO_2) savings is not as high as it might seem at first sight, and in some cases might even be negative. In fact, the raw materials for biofuels are normally obtained with intensive agriculture, which imply a high use of fertilizers, pesticides and machinery. Also, fossil fuels are used in the processing phase (oil pressing, trans-esterification) and for transporting the oil seeds to the processing plant and from there to the final users.

There are also disadvantages of large-scale biodiesel production. Due to the low yield, the land requirement is enormous. The Biomass Action Plan calculates that in order to achieve the 5.75% target (18.6 million tons biofuels) about 17 million hectares would be needed, i.e. one fifth of the European tillable land. Since there is not so much marginal and abandoned land in Europe, the consequence would be the substitution of food crops and a huge increase of food imports.[9]

For this reason, both in the Biomass Action Plan and in the EU Strategy for Biofuels it is stressed that Europe will promote the production of raw material for biofuels in extra-European countries. This means that the impacts of energy farming would be exported to Southern countries. It is easily foreseeable that if the European demand for biofuels increased because of biofuel obligations and other supporting policies, Southern countries may be stimulated to replace if not food crops at least native forests with large monocultures.

Energy farming would presumably have a big role in deforestation, because pristine forests would be cut down in order to cultivate energy crops. The consequences would include a reduction of wild biodiversity. Moreover, taking into account the CO_2 emissions due to inter-continental transport and the increase of CO_2 in the atmosphere due to deforestation (forests are CO_2 sinks), the final result might be an overall increase of the greenhouse emissions instead of the intended reduction. Also, a large scale biodiesel production would imply a strong environmental impact in the agricultural phase: the huge monocultures of energy crops would dramatically reduce agricultural biodiversity, with strong environmental impact in terms of soil erosion, use of fertilizers and pesticides, and water requirement. Also, one of the consequences may be an increase in the use of GMOs.

4. Conclusions

This paper has shown that the DPSIR framework is useful for structuring the analysis of the linkages between climate change as a pressure on biodiversity and the resulting consequences for biodiversity, ecosystem services and policy responses. As a result of a wide range of human activities, or driving forces, the concentrations of greenhouse gases in the atmosphere are increasing. This is leading to global and European surface air temperature increases (IPCC, 2001, 2007a). The potential consequences of further increased emissions are still not fully explored, but further temperature increases are expected, as well as rising sea levels, changes of precipitation, and more frequent occurrences of “extreme” weather events such as floods and droughts. All of these changes are pressures on biodiversity. Changes of climate together with other human activities will lead to the extinction or migration of species, loss of habitats, and fragmentation. Changes of biodiversity lead to

[8] http://ec.europa.eu/environment/climat/eccp_impacts.htm.

[9] Brown, L.R. 2006. Supermarkets and service stations now competing for grain. *Earth Policy Institute Eco-Economy Updates*. July 13. Available at http://www.earth-policy.org/Updates/2006/Update55.htm.

changes of ecosystem services and thus have impacts on human well-being. The response options are to mitigate climate change and to adapt to it. It is important, however, to ensure that climate mitigation and adaptation strategies are developed and implemented with the issue of biodiversity in mind. Climate adaptation and mitigation strategies that ignore the issue of biodiversity run the risk of undermining social and natural resilience. Linking biodiversity and climate change strategies offers co-benefits.

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