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CLIMATE CHANGE AND BIODIVERSITY FOR FOOD AND AGRICULTURE: TAKING SYSTEMIC AND SECOND ORDER EFFECTS INTO ACCOUNT

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Table of contents

Executive Summary

The present background study paper addresses the question what impact climate change has and will likely have on biodiversity for food and agriculture, and what are the specific challenges resulting from potential changes.

In line with FAO's general mandate, the study takes the problem of food security as its starting point and combines this concern with the concept of ecosystem services as they have been defined in the context of the Millennium Ecosystem Assessment (MEA 2005a). The term 'biodiversity for food and agriculture' is thus understood to imply a whole range of *ecosystems services* that are dependent on biological diversity and are at the same time critical for present and future food security.

After an introduction of the key concepts, the study looks at the direct, first-order effects of climate change on biodiversity for food and agriculture. To understand these effects it is necessary to first outline the predicted physical changes which will affect agro-ecological conditions and therewith have an impact on food production. Observed and projected changes of climate parameters are described on the basis of the WG I contribution to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC 2007a). Observations and projections are briefly summarized and, if necessary, supplemented by the latest research results (ch. 2.1.). The effects of changes in main climate parameters on biodiversity are then discussed separately for agriculture, forestry and fisheries, looking also into the differential impact on food security that can be expected in each field (ch. 2.2.).

It is a central argument of this study that the direct, first order effects of climate change on biodiversity for food and agriculture are only a part of the problem that has to be addressed. The study thus proceeds to explore and discuss also the *combined and systemic effects* of climate change on biodiversity-dependent ecosystem services that are critical for food security (ch. 3.1.). By analysing the potential impact of mitigation and adaptation measures currently under discussion (ch. 3.2.), it builds a strong case for also taking systemic and second order effects into account (ch. 3.3).

The key findings are then summarized in the concluding section (ch. 4). It is maintained that the impact of climate change on biodiversity for food and agriculture will not be a simple function of quasi-natural drivers and pre-existing social settings. Agricultural and environmental *policies* in the widest sense will be an important factor with more than just a mediating role, influencing the available options of vulnerable groups in rural and urban settings alike. The main challenge for national and international bodies with regard to biodiversity for food and agriculture then is to address the second order, largely policy-related effects in an adequate manner so as to minimize their inherent risks for the most vulnerable groups and make the best use of the opportunities that are opening up, in particular in the expected dynamics of land use change.

1. Introduction

1.1. Food security and climate change

Food security can be defined as the availability, accessibility, stability and utilization of sufficient, safe and nutritious food for all people. Food security is the positive outcome of *food system performance*, defined as set of interactions between bio-geophysical and human environments influencing the production, storage, processing, distribution, exchange, preparation and consumption of food (FAO 2007a, p. 4).

Recent climatic changes, which are very likely to be caused by human activities (burning of fossil fuels, deforestation), have the potential to fundamentally affect food security by changing conditions on all geographic levels and for all components of food security. Therefore, any attempt to adapt food systems to climate change necessarily involves several components of food security; measures solely focussing on technical solutions for enhanced food production can not meet the complex adaptation needs in other areas of food security (Ericksen et al 2009, p. 375). Although climate change impacts in their influence on agro-ecological production conditions are most obvious for the production dimension of food security, they are not limited to this dimension: also the access to, stability and utilization of food are projected to be influenced by climate change (Schmidhuber and Tubiello 2007, p. 19703ff.).

- As production in agriculture, forestry and fisheries is dependent on ecosystem services, *food availability* in general is sensitive to climate variability and climate change. This sensitivity is due to direct effects of climate change on agro-ecological conditions, e.g. through more frequent extreme weather events, rising sea levels, changing mean temperatures and precipitation patterns (FAO 2007a, p. 5) and, in the case of fisheries, through ocean acidification and changes in current regimes (Nellemann *et al.* 2008). Climate change is projected to not only influence food production directly, but also to interfere with socio-economic variables like economic growth and income distribution, leading to changes in the demand for food products and thereby changing food production (Schmidhuber and Tubiello 2007, p. 19703);
- *Food stability* is still mainly influenced by direct climate change drivers. More frequent extreme weather events, leading to short-term fluctuations of crop yields and to damages to transport and distribution infrastructure, may regionally disrupt food supply chains, endanger the stability of food supply and so threaten food security. Dominant causes for short-term fluctuations in food production are droughts and floods, both of which are projected to become more frequent through climate change (IPCC 2007b, ch. 5.4.1 to 5.4.5). Profound regional differences in exposure and vulnerability of production systems to extreme weather events are expected, leaving semiarid and arid regions in Africa and Asia with the most serious threats of temporary food shortages;
- Climate change effects on *food utilization* are mainly anticipated in the context of spreading vector-, water- and food-borne diseases, with the two latter being of particular relevance to food safety. Increases in mean air and water temperatures, temperature variability, and the frequency of extreme rainfall and flooding events are expected to result in a growing number of food poisoning incidences, diarrhoeal disease episodes and outbreaks of water-borne diseases, such as cholera. In

combination with an already prevalent undernourishment, the growing occurrence of infectious diseases could contribute to a decline in labor productivity, and to growing poverty and food insecurity (Schmidhuber and Tubiello 2007, p. 19705);

- Whereas the former elements of food security are arguably mainly affected by direct climate change effects, changes in *food accessibility* are projected to be mainly based on modifications of socio-economic structures. FAO estimates for 2050 assume global improvements in the accessibility of food, especially in regions currently showing relatively high numbers of malnutrition. Driven mainly by endogenous or exogenous income growth, the proportion of undernourished people in developing countries could be reduced from roughly 20 % in 1990/1992 to only around 4 percent in 2050 (FAO 2006, p. 4). However, climate change effects potentially counteract such improvements in food accessibility. Climate change could negatively affect global economic growth, and thereby interact with income-generating capacities and employment opportunities of individual households. In combination with a projected rise of food prices (e.g. caused by climate change-induced pressures on production resources or land use competition through expanded mitigation practices), access to food could be seriously diminished by climate change effects (FAO 2007a, p. 6f.).

Climate change effects on food security will *not be distributed evenly*, neither across nations and regions, nor among social groups. Projections still bear substantial uncertainties, especially with regard to the question how global trends will be reflected in local changes.

- Most probably, direct climate change parameters, such as increasing atmospheric CO_2-levels and rising temperatures, will positively influence food production in temperate regions, whereas *low-latitude-regions* are going to suffer from temperature rise and intensification of drought periods. Although food production on a global scale might therefore remain relatively stable, low-income-countries with lacking trading capacities (or limited trading power) could be increasingly dependent on foreign food aid (IPCC 2007b, p. 276; FAO 2007a, p. 6);
- At the same time, climate change will probably most severely affect food security of those individuals and communities that are less capable of adapting to changing environmental conditions. Although precise knowledge about possible climate change impacts on different production systems is relatively small, research suggests that the complexity of interactions between a comparatively high variety of crops utilized in smallholder and subsistence agriculture disadvantages this production form over more commercialized, large-scale farming methods with a limited range of crops. *Small-scale farming* might consequently be more sensitive to changes in key climate parameters. Yet other factors (family labor, income diversification besides agriculture, indigenous and local knowledge) could act as counterbalance to a high sensitivity towards environmental stress (Morton 2007, p. 19684);
- Hotspots of potential climate change impacts on food security can be determined by identifying regions where climate-sensitive food crops coincide with a high importance of these crops for a region's food systems. Lobell *et al.* (2008) compile projections of climate change impacts on different crops with information on the crop's importance for a region's food-insecure population, which allows them to identify crops and regions for which adaptation measures are essential to avert

short- and medium-term food crises (e.g. wheat in South Asia, Sahel sorghum, Southern African maize etc.).

1.2. Food security, ecosystem services and biodiversity

Food security is often directly or indirectly dependent on "ecosystem services" (FAO 2007a, p. 4). The term ecosystem services does not only include the direct provisioning of food and other goods as basis of food production; it also encompasses indirect functions that are essential to human well-being (MEA 2005a, p. 1; CBD 2003, p. 1):

- *Provisioning services* related to food production, and also to water, fuel wood, fibres, biochemicals, medicines, and genetic resources;
- *Supporting services* such as soil formation and protection, photosynthesis, water and nutrient cycling;
- *Regulating services* with regard to climate and extreme weather events (floods, droughts, fires), biological control of pests and diseases, waste treatment, pollination, and water quality regulation;
- *Cultural services* such as options for recreation, aesthetic enjoyment, cultural diversity and identity, or knowledge systems.

Ecosystem services are therefore not only relevant to production but also affect vulnerability and food security in a broader, fundamental way.

An intrinsic element of the MEA´s conceptual design of "ecosystem", especially regarding the potential of providing humans with ecosystem services, is biodiversity:

> *"Biodiversity […] is essential for the functioning of ecosystems that underpin the provision of ecosystem services that ultimately affect human well being."* (MEA 2005a, p. 1)

In this line of reasoning, there is a direct connection between biodiversity and different elements of *human well-being* (specified by the MEA as basic materials, health, security, social relations, and freedom of choice and action).

In accordance with the Convention on Biological Diversity (CBD), the term biodiversity is understood here in a broad sense, encompassing the genetic variability within and between species, and of ecosystems as well as between them. This multiscalar and multidimensional approach of defining biodiversity, in recognition of its spatial and temporal variations, is the precondition for

> *"[…] insights into the relationship between changes in biodiversity and changes in ecosystem functioning and ecosystem services."* (*ibid.*, p. 18)

Human activities have caused significant changes in ecosystems, and many of these changes have resulted in *biodiversity loss*. Losses have accelerated over the last decades, mainly due to habitat changes, climatic change, pollution, overexploitation, and the destructive effects of invasive species. Over the past few hundred years, human activities have increased species extinction rates by a factor of 1,000 (*ibid.*, p. 4), compared to historical background rates.

Climate change is predicted to become one of the main factors causing losses at different levels of biodiversity in the future. Although currently exceeded by other anthropogenic pressures, climate change effects on biodiversity are expected to gain importance in the course of the century. Most obvious effects of changes in key climate parameters on biodiversity are derived from shifts of ecosystem boundaries through changes in precipitation, temperature or sea level rise. As a result, some ecosystems might expand into new areas, while others will recede or even completely disappear. As some species will not be able to adapt to habitat changes, *shifting ecosystem boundaries* will have clear impacts on biological diversity. Species with small populations, or populations with small habitats, will be especially vulnerable to climate change (Reid and Swiderska 2008, p. 2).

Most *rapid changes*, for which adaptation is most difficult, are expected to occur in high-latitude and in mountainous regions. Changes in ecosystem boundaries here are particularly threatening, as many species are highly adapted to prevailing environmental conditions, making it difficult to readapt to new situations (*ibid.*, p. 2).

2. First-order effects of climate change on biodiversity for food and agriculture

Climate change is considered to be one of the main factors reducing biodiversity by the end of the century (MEA 2005a, p.4). The IPCC estimates that 20-30% of all species are likely to be exposed to a higher risk of extinction with a temperature rise exceeding 2-3°C, resulting in substantial changes in ecosystem composition and functions (IPCC 2007b, p. 213). Those trends describe *general risks* without differentiating between threats for biodiversity in the different sectors of food production (agriculture and livestock, forestry, fisheries) and effects on biodiversity in wild ecosystems. Climate change impacts will affect both components of biodiversity, with different consequences for food security. The specific connections between climate change, biodiversity losses *in the different sectors* of food production and their implications for food security have rarely been addressed in present climate change debates.

Changes in the composition of unmanaged or *largely unmanaged ecosystems* will affect food security in two basic ways:

- By altering the resource base, climate change will affect food production that is directly dependent on provisioning services of natural ecosystems. E.g., a large proportion of the fisheries sector is still dependent on wild fish stocks, making it vulnerable to changes in the composition of these ecosystems (Brander 2007, p. 19709). Changes will also affect the food security of rural communities whose livelihoods are dependent on gathering wild or semi-wild plants for food, health, clothing or shelter. Climate change might also increase their dependency on wild products, making the rural poor in developed countries even more vulnerable to changes in ecosystem composition (Reid and Swiderska 2008, p. 3);
- Food production in the different sectors is strongly dependent on ecosystem services derived from wild or largely uncultivated biodiversity, e.g. communities of soil organisms or pollinators. Below-surface biodiversity (biodiversity in soils as well as in marine and freshwater sediments) is a precondition of fertile habitats for food and fibre. By contributing to nutrient-cycling, aerating of soils, decreasing of erosion and other ecosystem services, below-surface organisms play a crucial role in all sectors of food production that can only be fulfilled by diverse below-surface and associated above-surface biotic communities (UNESCO and SCOPE 2007, p. 2). In some cases, low fruit or seed sets of crops and associated yield reductions can be

attributed to an impoverishment of pollinators, indicating that production levels of food crops can be affected directly by the number and diversity of pollinators (Hajjar *et al.* 2008, p. 263).

The effects of climate change on 'wild' biodiversity are thus not confined to extractivist modes of production. By changing or endangering ecosystem services that are crucial for entire food production systems, they are likely to also affect the state and performance of *biodiversity for food and agriculture* in a more narrow sense.

2.1. Main climate change parameters affecting biodiversity for food and agriculture

In order to understand the physical basis of those impacts, a brief overview of changes in key parameters of climate change is given on the basis of the latest IPCC reports. According to recent observations, however, these parameters range near the upper boundaries of the IPCC projections (Richardson *et al.* 2009, p. 6). Trends presented here are therefore likely to be rather conservative estimates.

2.1.1. Increasing atmospheric CO_2-levels

CO_2-levels play a crucial role for many other climate change parameters, as CO_2, once released to the atmosphere, rapidly interacts with terrestrial biosphere and surface ocean. Direct and indirect measurements of past and present CO_2-levels show that the atmospheric mixing ratio of carbon dioxide has significantly increased since 1750. Increases are quantified as follows: from a range of 275 to 285 ppm in the pre-industrial era, CO_2-concentrations grew to 379 ppm in 2005, which means a total growth of 100 ppm in ~250 years. The growth rate of CO_2-concentrations has dramatically accelerated towards the end of the 20th century: whereas the first 50ppm of the total growth were reached by the end of the 1970s, an increase of another 50ppm took place in less than 30 years since then. Increases are mainly attributed to the burning of fossil fuels, to gas flaring and cement production, but also to land use changes (e.g. deforestation) and biomass burning. Together with increasing concentrations of other greenhouse gases (methane, nitrous oxide, halocarbons) and in combination with changes in the amount of water vapour and aerosols, CO_2 alters incoming and outgoing *radiation*. This significantly impacts the Earth's energy balance, contributing to the observed global warming (IPCC 2007a, p. 135ff.). Any projection of future climate change directly depends on different emission scenarios, which try to determine further changes in greenhouse gas (GHG) concentrations in the atmosphere. If GHG emissions continue on or even exceed current levels, this

> "[…] will cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century." (*ibid.*, p. 748)

2.1.2. Rising temperatures

Observations of *surface temperature* rises over the last 100 years show a clear upward trend, with a total temperature increase of 0.76°C since 1899. The second half of the last century thereby showed a warming rate of 0.10°C to 0.16°C per decade, almost twice as high as the average warming rate for the whole century. The twelve years from 1995 to 2006 saw eleven of the warmest years since the instrumental record of surface temperature (IPCC 2007a, p. 252f.).

Projections for the years until 2100 show large variations. Most optimistic projections expect global temperature rises in a range of 1.1 to 2.9°C, whereas under non-mitigation scenarios temperatures are expected to rise from 2.4 to as much as 6.4° C (*ibid.*, p. 749).

2.1.3. Changes in precipitation patterns

Observed changes in precipitation differ significantly between regions. While precipitation in temperate regions has generally increased from 1900 to 2005, the tropics show a persistent decline of precipitation from the mid 1970s onwards (IPCC 2007a, p. 254ff.). An *increasing frequency of drought events* has been ascribed to those changes.

Although projections for the 21st century suggest that the global mean precipitation is going to grow, *strong regional differences* are expected. General trends observed in the late 20th century are projected to continue. Increases in the amount of precipitation in high latitudes are very likely, while low latitudes (especially subtropical regions) are likely to experience a further decline of up to 20% until 2100 (*ibid.*, p. 768).

2.1.4. Sea level rise

While sea level has been relatively constant during the last 2,000 years, the 20th century saw a gradual change of this stability (Johnson *et al.* 2008, p. 226). From 1961 to 2003, sea level rose with an average rate of 1.8mm per year, with a clear *acceleration* during the period from 1993 to 2003 (average rate: 3.1mm p.a.). The two main reasons for sea level rise are the expansion of oceanic water due to increasing water temperatures and the loss of land-based ice due to increased melting (IPCC 2007a, p. 409ff.).

Depending on the emission scenario, the projected range for sea level rise in the 21st century lies between 0.18 and 0.59 m. Recent studies allow the assumption that these estimates are rather conservative. Johnson *et al.* (2008) show that the rate of Antarctic ice mass losses has been dramatically higher during the years from 1992 to 1996 (with an average thickness loss rate of 1.6 meters p.a.), compared to the average rate of the last 5,000 years (between 2.3 and 3.8 centimetres thickness p.a.). Although it is unclear whether the unexpectedly high loss rate reflects a general trend or fluctuations are of temporary nature, the dramatic increase of ice losses could indicate an even *faster rise* of the sea level than expected by the latest IPCC report.

2.1.5. Increasing frequency and intensity of extreme weather events

Extreme weather events include heavy precipitation and droughts, temperature extremes, as well as tropical and extratropical storms. Although spatially inconsistent, heavy precipitation events have been increasing in many regions, also where precipitation in general has decreased. At the same time, reduced precipitation coinciding with increased evaporation due to rising temperatures has led to more areas experiencing droughts. Extremes of warm temperature have increased in most regions, whereas the numbers of frost days and daily cold extremes have generally decreased. Temperature extremes are consistent with general warming trends. Tropical storms show clear upward trends with regard to *storm intensity and duration* since the 1970s, leading to a rising destructiveness of storm events. However, strong regional differences in the total number of storms have to be considered, with highest growing rates in the North Pacific, Indian and Southwest Pacific oceans. Since the 1960s, storms have also increased in mid-latitude regions, although in the late 1990s, levels have gone back to normal in the Northern Hemisphere (IPCC 2007a, p. 237ff.).

Trends observed for heavy precipitation events and heat waves are projected to continue, leading to an increased risk of more severe, more frequent and longer *heat waves*, as well as to higher temporary rainfall intensity and corresponding *flooding* in the future. Projections for storms show reduced total numbers of tropical as well as extratropical storms, but the intensity of storms is expected to rise with regard to wind speed and precipitation (*ibid.*, p. 782ff.).

2.1.6. Ocean acidification

Increasing atmospheric CO_2 concentrations have direct effects on the ocean's pH-level. Currently, pH values of the ocean surface are already 0.1 units lower than in pre-industrial times. Direct observations over the last 20 years show a *decrease of oceanic pH-levels* of 0.02 units per decade. Ocean acidification influences the chemical composition of the ocean, e.g. the saturation with calcium carbonate, which is especially threatening to marine organisms and ecosystems (IPCC 2007a, p. 387).

For the 21st century, acidification is projected to continue with an expected decrease of oceanic pH-levels between 0.14 and 0.35 units, which means a clear acceleration of ocean acidification. *Southern ocean surface waters* will be especially exposed to a decreasing calcium carbonate saturation, although low-latitude regions will be affected as well. Furthermore, the penetration of atmospheric CO_2 into the *deep sea* is expected to change the chemistry down to several thousands of meters (*ibid.*, p. 793).

2.1.7. Changes in oceanic current regimes

Little is known about the impact of climate change on local or regional current regimes, but changing wind and precipitation conditions allow the assumption that currents already change on this scale. Climate change impact on *global current regimes and circulation* is a matter of considerable debate. So far, there is no clear evidence of ocean circulation changes, although temperature variations have been documented in Southern Ocean mode and deeper circulation waters, as well as the Gulf Stream in the North Atlantic and North Pacific (IPCC 2007a, p. 387).

For local changes of ocean currents, *uncertainties* in projections are high, but expected growth of strong wind and heavy precipitation events might influence local regimes. During the 21st century, the Atlantic Ocean Meridional Overturning Circulation (MOC) is very likely to slow down, but estimates range from virtually no changes to a reduction up to of 50% by 2100. A complete breakdown of MOC is not expected (*ibid.*, p. 752).

2.2. Agricultural biodiversity and climate change

2.2.1. Effects of changes in main climate parameters on agricultural biodiversity

It is clear that climate change will generally impact food and agriculture, and also specifically the biodiversity of food crops and animal breeds under human management. Climate change parameters (especially rising temperatures and changing precipitation patterns) will cause geographical *shifts of possible vegetation ranges* for plant species and varieties. Impacts on agricultural production will depend heavily on geographic location, as range shifts can lead to both, improvement and deterioration of growing conditions. Moderate warming is projected to benefit crop and pasture yields in mid- to high-latitude regions, whereas yields in seasonally dry and tropical regions will suffer from an even slight warming. Above a global warming of 3° C, food production is projected to decrease worldwide (IPCC 2007b, chapter 5.2-5.6).

If no adaptation measures were taken, rising temperatures and changing precipitation would likely cause *local extinctions* of food crops, as suitable farming areas decrease or disappear (*ibid.*, p. 299). This is especially threatening where the varietal diversity of a crop is high. In some cases, climate change is projected to threaten primary or secondary centres of genetic diversity of certain crops, seriously endangering their diversity on a global level. *In-situ* conservation of such vulnerable species with little capacity to migrate (e.g. Arachis sp.) may require targeted human intervention and, in some cases, translocation (Jarvis *et al.* 2008).

For adapting food crops to changing environmental conditions, constant access to plant genetic resources is needed. Crop wild relatives could play a crucial role in providing farmers with this access. By influencing growth and reproduction rates and by limiting locally available resources, climate change has the potential to affect crop wild relatives. Jarvis *et al.* (2008) combine climate change projections with species distribution models to analyze possible extinctions of wild relatives of peanut, potato and cowpea by 2055. They are able to show that climate change will strongly affect the relatives of all three taxa. Depending on different migration scenarios, 16-22% of all researched species are predicted to go extinct, as suitable growing areas disappear or get out of reach (*ibid.*).

Extreme weather events have the potential to seriously affect food security by disrupting local food production and by damaging infrastructure for food supply (IPCC 2007b, ch. 5.4.1). The biodiversity of food crops might suffer from a higher frequency of extreme weather events, as single crops might not be able to adapt to frequent flooding or drought events. The extent of anthropogenic interventions in areas affected by extreme weather events might play a critical role for the conservation of agro-biodiversity: in such situations of sudden and abrupt changes in ecosystem functioning, human reactions can heavily influence in which way ecosystems will recover.

Coastal ecosystems are highly sensitive to variations in weather and climate (*ibid.*, p. 335). Sea level rise contributes to a generally high vulnerability of coastal areas to climate change parameters. It is unclear in how far *sea level changes* pose an additional threat to the biodiversity of food crops, but threats to wild relatives of crops in coastal and halophytic habitats like wild beets (Beta vulgaris ssp. maritima) seem rather likely.

The global situation of *livestock breeds* has only recently been assessed (FAO 2007b). In most regions of the world, ‘local breeds’ (i.e., according to FAO’s definition, those occurring in only one country) make up for more than two thirds of all breeds. 190 of around 7600 breeds recorded in FAO-reports have become extinct during the past 15 years, with around 1500 more breeds classified to be at *risk of extinction*. For the last five years, an average loss rate of one breed per month has reduced the number of cattle, goat, pig, horse and poultry breeds by a total number of 62 (*ibid.*, p.5).

Although threats for animal genetic resources are mainly seen in the *marginalization of traditional production systems* and their breeds by high-output, industrialized livestock production, climate change aspects might pose additional threats to livestock biodiversity. Regionally, a combination of rising temperatures with reduced precipitation might add on selective breed losses due to changes in production systems. An increased frequency of droughts or floods could result in the loss of entire breeds with limited geographic distribution. Furthermore, climate change might contribute to the *spread of new animal diseases*, which could also lead to higher mortality rates and selective losses among breeds.

High rates of losses will especially occur among *indigenous breeds* in developing countries, where management programs for the conservation of biological diversity in livestock are often missing. This will result in reduced livelihood options for the poor (ILRI 2007, p. 31).

2.2.2. Differential impact on food security

The strongest impact of climate change on *growing capacities* is expected among the poorest countries. A combination of rising temperatures with decreasing rainfalls, as predicted for Sahelian countries, will reduce vegetation periods and thus hinder plants to complete their vegetation cycle (IPCC 2007b, p. 104). It is estimated that, by 2080, the 40 poorest countries (mainly located in tropical Africa and Latin America) are going to suffer a loss of 10 to 20 percent of their basic grain growing capacity. Rain-fed crops in tropical Africa and Latin America are predicted to reach their maximum temperature tolerance (Kotschi 2007, p. 99).

Generally, impacts of global drivers of change are expected to be felt especially in diverse agro-pastoral, smallholder crop-livestock systems. This is mainly due to a *stronger dependency* of these systems on the local natural resource base, whereas intensified industrialized food production systems specializing on a limited numbers of crops or livestock breeds tend to be less dependent on changes in local resources (Thornton *et al.* 2006, p. 2).

At the same time, marginal smallholder and subsistence farmers in countries and areas that are likely to be most exposed to the immediate effects of climate change may have a range of adaptation options at hand. Thus, they are not automatically the most vulnerable groups. In particular, the high diversity, including biological diversity, of many traditional systems, the amount of local or indigenous knowledge available, and robust, adaptive institutions can form the basis of successful *coping strategies* that provide for food security also under conditions of climate change. Yet the links between the overall biological diversity used in particular systems of food production and the productivity of these systems on the one hand, and their adaptability on the other, are not simple or clear-cut. In some cases, ‘modern’, low diversity systems may be more readily transformed, shifted or replaced than socially anchored, highly diverse systems. As a general starting point, however, it seems reasonable to aim at economic diversification in most instances to reduce dependence on climate sensitive resources, and at portfolio strategies including a high degree of diversity also in the biological components of the system (cf. Kotschi 2007).

The impact of climate change on biodiversity for food and agriculture is not a direct product of natural factors and given social settings. Agricultural and environmental *policies* in the widest sense will also play an important role and heavily influence the available options of vulnerable groups in rural as well as urban settings. Among the dimensions that are affected, land use planning, issues of tenure, and the financial incentives for particular products, production systems or environmental services are of outstanding importance.

2.3. Forest biodiversity and climate change

2.3.1. Effects of changes in main climate parameters on forest biodiversity

Observations of current changes in community organization, shifts of vegetation zones, changed seasonal patterns, and productivity fluctuations of certain forest systems show that climate change already affects forest ecosystems. Generally, predictions suggest that climate change effects will add onto negative effects human activities already have on forest biodiversity. Forest losses tend to occur in low-income, tropical countries, where primary forests have been decreasing by annually 6 mill. ha since 1990. Climate change will deepen the adverse impact of *forest cover loss* and will contribute to ecosystem losses and gradual changes in forest species composition (CBD 2007, p. 4).

While experimental designs show positive effects of increased atmospheric CO_2 concentrations on productivity of forest species, little is known about possible interactions between different field parameters and the *"carbon fertilization effect"*. For example, productivity gains projected for Northern Asia are likely to be offset by adverse changes in other climate-related parameters (increased forest fires, extreme weather events) (*ibid.*, p.4). Furthermore, it is still unclear in how far increasing atmospheric CO_2 levels will favor certain forest species over others, thus possibly leading to changes in ecosystem composition and threatening forest biodiversity.

Changes in precipitation patterns and surface and soil temperature will result in *shifts of potential vegetation zones*, for both natural and managed or modified forests. Boreal zones are projected to shift as far as 500 km in polar-ward direction, opening up vast areas of land for forest expansion at the Northern limit of the boreal zone, but at the same time leaving forest areas at the opposed boundary of the vegetation zone unsuitable for certain forest species. With regard to forest biodiversity, the question of lagged forest migration is crucial. A projected vegetation zone shift of around 50 km per decade outpaces many tree species' migration rates of only few kilometres per decade (derived from analyzes of forest migration after the last glacial period), leading to potentially dramatic forest losses. It is expected that especially unmanaged forests will thus lag behind vegetation zone shifts, whereas managed forests might suffer to a lesser extent, as their migration can be facilitated by human action (Kirilenko and Sedjo 2007, p. 19697).

An increased *frequency of extreme weather events* has multiple impacts on forest ecosystems, reaching from smaller damages (branch breaking, crown loss) to single trees through wind, snow frost or ice, to the loss of trees or complete stand destruction (IPCC 2007b, p. 290). This counts especially for *fragmented forests*, which are specifically vulnerable to windfall. For example, mortality rates due to hurricanes in Costa Rica have recently been calculated to be seven times higher than in the past (CBD 2007, p. 4). Habitats already under anthropogenic stress might therefore be decisively damaged through climate change effects, resulting in irrecoverable biodiversity loss.

The number of *forest fires* is projected to increase with climate change, mainly because of changing precipitation patterns, increasing drought events, and rising temperatures. Projections for Canada show a possible doubling of burned areas by the end of the century (Kirilenko and Sedjo, 2007, p. 19698). Wild biodiversity might be affected more seriously by forest fires, as most of the fire damage is expected in remote, unmanaged areas.

It is very likely that climate change parameters (primarily rising temperatures and changing precipitation patterns) will also affect the *outbreak of pests and diseases* in silviculture. Growing infection rates can result in defoliation and reduced growth, and may culminate in massive forest diebacks (*ibid.*). Observations in North America demonstrate that earlier spring events have already led to an increased productiveness and ongoing diffusion of certain insect species, e.g. the mountain pine beetle, resulting in growing mortality rates among tree stands (CBD 2007, p. 4).

By increasing salinity and the frequency of flooding, *sea level rise* will affect coastal forest ecosystems. Regeneration periods will be reduced and trees, including mangroves, will suffer from *salt water intrusion* (IPCC 2007b, p. 333). For example, local extinctions of mangrove species might occur in Antigua and Barbuda as soon as 2030 (CBD 2007, p. 5).

2.3.2. Differential impact on food security

Global trends in climate change and their effects on forest biodiversity will not play out homogenously, but differ significantly on a regional level. Local or regional biodiversity changes will furthermore have widely *differing impacts on food security* of affected individuals and social groups, mainly due to varying degrees of dependency on forest resources among different users.

Forest ecosystems which are expected to experience the most significant losses of biodiversity and, thus, show the most serious reduction of ecosystem services include mangroves, boreal forests, dry forests, tropical forests and cloud forests (CBD 2007, p. 5). Isolated and fragmented forests are expected to show less resilience to extreme events than large-scale, coherent forests, as the *connectivity* among different ecosystems is a precondition for their adaptation through introgressive hybridization.

Climate change is projected to have slightly *positive effects* on commercial forestry's global productivity. If positive CO_2-effects are considered in modelling, timber yields generally increase, but regional and local differences in production gains will be large. In the short-term, production benefits will be derived in low-latitude regions but shift to high-latitude regions in the longer run. Income benefits of increased forest productivity will follow the regional shift, although timber producers might increasingly suffer from declining wood prices (IPCC 2007b, p. 288ff.). However, projections bear uncertainties, as the carbon fertilization effect might be overestimated in modelling experiments or be offset by limiting factors, as pests, weeds, competition for resources, soil water, air quality, etc. (Kirilenko and Sedjo 2007, p. 19700). Additionally, wood price predictions bear substantial uncertainties i.a. due to their links with energy prices.

Even though the overall monetary benefits from forests are likely to exceed losses in the mid-term, the loss of forest resources, and forest-related biodiversity, may directly affect 90 percent of the 1.2 billion *forest-dependent people* who live in extreme poverty (IPCC 2007b, p. 291).

While timber productivity gains may be achieved despite of climate change-induced biodiversity loss, a number of other *ecosystem services* will seriously suffer from ecosystem changes, leading to possible negative food security impacts for forest-dependent communities.

- Little is known e.g. about the impact of climate change and biodiversity loss on *non-timber forest products* (fuel wood, forest food like berries and roots, or medical plants), but it can be argued that livelihoods of forest-based communities in developing countries which are dependent on diversified forest products are particularly sensitive to environmental changes and shifts in species composition (*ibid.*, p. 291);
- Corresponding effects may be multiplied by the accompanying devaluation or loss of *indigenous and local knowledge* about the natural world. Biodiversity loss and changes in provisioning ecosystem services might therefore contribute to rising food insecurity (through decreasing availability and accessibility of food) among those groups.

2.4. Biodiversity in fisheries and climate change

2.4.1. Effects of changes in main climate parameters on fisheries biodiversity

Changes in key climate parameters are expected to fundamentally change the distribution, abundance and productivity of fish species, culminating in local species losses. These local extinctions are especially expected at "the edges of ranges, particularly in freshwater and diadromous species" (IPCC 2007b, ch. 5.4.6). Sub-polar regions, the tropics and semi-enclosed seas might therefore experience local extinctions, whereas ecosystems in the Arctic and Southern Ocean will have to face intense species invasions (Cheung et al. 2009).

Fisheries are generally more vulnerable to changes in species composition, as a lot of species are utilized. Food production is directly dependent on a relatively high number of species (220 reported aquatic animal and plant species in 2002) in comparison to agricultural and silvicultural production, where the main part of production is derived from a rather limited number of plant and animal species (Brander 2007, p. 19709).

In contrast to land based activities, fisheries are still strongly dependent on wild, rather than controlled, species stocks and need functioning *natural or quasi-natural ecosystems*. In 2005, roughly two thirds of the total production of fish, molluscs, and crustaceans were derived from capture fisheries, whereas the remaining third came from aquaculture production (FAO, n.d.). Adaptation measures are therefore more complex.

Direct drivers affecting *marine ecosystems* include ocean warming, sea level rise, increase in wave height and frequency, loss of sea ice, increased risk of diseases in marine biota and decreases in the pH and carbonate ion concentration of surface oceans (IPPC 2007b, p. 234f.). Climate change drivers impact marine ecosystems globally, with *high cumulative impacts* and with particular importance for offshore habitats (Halpern *et al.* 2008, p. 950). The different factors directly influence physiology, behaviour, growth, reproductive capacity, mortality and distribution of fish stocks (Brander 2007, p. 19710).

- *Increasing sea temperatures* already cause movements of plankton, fish and other species in pole-ward direction. Examples of such movements have been recorded for plankton in the Northeast Atlantic, or for a number of warm temperate and subtropical fish species moving along the continental slope to the west of Europe (Nellemann *et al.* 2008, p. 38). Further changes in migration routes and in the productivity of fish stocks are expected with continuing warming, which might be responsible for a local *loss of fish species* (Brander 2007, p. 19710). At the same time, range shifts through changing temperatures might also favour the extension of invasive species into new marine ecosystems, posing additional threats to biodiversity;
- Another effect of rising sea surface temperatures is the occurrence of *coral bleaching* events, which have been recorded at several locations since 1998 and in the meantime affect the majority of tropical reefs (Hoegh-Guldberg *et al.* 2008). During those events, symbiotic algae living in coral tissues are displaced, leading to a die-off of large proportions of the riff organisms and a fundamental change in ecosystem composition. Diverse riff ecosystems are turned into impoverished, algae-dominated marine communities (Nellemann *et al.* 2008, p. 29). In the long run, the reduced complexity of reef structures leads to a decline of reef fish species richness (IPCC 2007b, p. 854);

- The effects of increased *oceanic acidification* due to a gradually rising uptake of anthropogenic carbon by the oceans are poorly documented. Declining pH-levels will affect marine organisms with calcified shells, bones or skeletons. For example, any part of coral skeletons exposed to more acidic ocean waters will be corroded, which might be the case for 75 percent of all cold-water corals by 2100. Dramatic impacts could follow from changes in low trophic levels of marine ecosystems. If vulnerable planktonic organisms are affected by ocean acidification, marine food web relations might fundamentally change, which would impact higher trophic levels and might alter ecosystem composition (Nellemann *et al.* 2008, p. 35f.);
- *Changes in oceanic currents* might change migration routes of fish communities, lead to altered transport routes for eggs and larvae, and generally be responsible for shifts of bioregional zones in the oceans. On a global scale, evidence grows that climate change could cause a slow-down of thermohaline circulation. Although little is known about critical thresholds causing abrupt and fundamental changes of Meridional Overturning Circulation (MOC), also slight changes could impact marine ecosystem productivity, ocean chemistry and cause shifts in ecosystem composition for fisheries (MacKenzie *et al.* 2007, Nellemann *et al.* 2008, p. 40);
- The introduction of *invasive species*, which can be promoted by climate change factors (temperature and current changes) has dramatic effects on biodiversity of marine ecosystems, their biological productivity and habitat structure and therefore also affects fisheries. Although there is no evidence that invasive species have caused extinctions of marine species, the relative abundance of marine communities might be completely altered by invasive species (Nellemann *et al.* 2008, p. 53);
- Further effects on biodiversity of marine ecosystems are expected from climate change impacts on coastal areas. A higher frequency of *extreme weather events* (coastal areas are highly exposed to floods, cyclones and tidal waves) and a rising sea level can lead to *habitat degradation* and eutrophication of coastal ecosystems and increase silt and algae coverage of corals, leading to the disappearance of ecological niches and important *hatching grounds* of marine biota.

Although of minor importance in comparison to food production in capture fisheries, *inland fisheries* are an important source of protein in many countries. Freshwater habitats are highly fragmented and include smaller and genetically more subdivided fish populations. Therefore, the biodiversity of *freshwater ecosystems* and related food production from fisheries face specific challenges from climate change (Grant 2007, p. 38f.). In combination with other anthropogenic pressures (e.g. human alterations of river flows, water withdrawal), climate change has already caused faster biodiversity declines than in terrestrial or marine ecosystems over the past 30 years (Xenopolous *et al.* 2005, p. 1557). Meanwhile, approximately 20% of the world’s freshwater fish species have been listed as threatened, endangered, or extinct (MEA 2005c, p. 27).

- Generally, freshwater species in both lotic and lentic systems will be exposed to *rising water temperatures*, due to global temperature increase. Growth, reproduction and activity of freshwater fish are affected by rising temperatures. This means that individuals face changes regarding their metabolism, food consumption and reproductive successes. Fish populations exposed to rising water temperatures might experience range shifts, culminating in extinction. Furthermore, rising water temperatures limit levels of dissolved oxygen. Although depending on a high number of other local factors, rising water temperatures are likely to cause decreased dissolved oxygen in at least some systems, which can lead to an "oxygen squeeze" when decreased oxygen levels in the water cannot meet increased oxygen demand of fishes (Ficke *et al.* 2007, p. 583);

- Through repercussions on freshwater aquifers, *sea level rise* will add on changing hydrologic regimes and thereby contribute to alterations of freshwater habitats and associated biodiversity losses (MEA 2005c, p. 1);
- In lotic systems, changed *precipitation patterns* and increased *evaporation* can affect water regimes and alter water availability (Ficke et al 2007, p. 581). While 70 percent of the world's rivers are projected to experience increased water availability (e.g. due to increased precipitation in higher latitudes), the remaining 30 percent of the rivers will be negatively affected by climate change. Fundamental changes in water regimes might cause the loss of a significant share of species in these basins by 2100 (MEA 2005b, p. 377). Recent studies show that up to three quarters of local fish species in rivers with reduced water flow are threatened with extinction by 2070. Climate change plays a crucial role in reducing river discharge, while interlinkages with human water withdrawal and other additional anthropogenic pressures are projected to exacerbate regime changes and lead to even higher extinction rates (Xenopolous *et al.* 2005, p. 1561).

The rapidly growing sector of *aquaculture* will also be affected by climate change parameters:

- Many of the threats mentioned above for inland and marine fisheries also affect aquaculture. Rising temperatures might be responsible for events similar to the "oxygen sqeeze" in freshwater ecosystems, when sinking oxygen levels in the water coincide with a rising oxygen demand of fishes. Changing precipitation can endanger water supply for aquaculture in some regions, while in other regions areas suitable for aquaculture could expand. Especially in coastal areas, aquaculture will likely be further affected by salinization, sea level rise and the increasing occurrence of extreme weather events (Brander 2007, p. 19711);
- Besides that, aquaculture is strongly dependent on the availability of fishmeal and oils from capture fisheries, making it directly vulnerable to climate-change induced alterations in the productivity of capture fisheries (Brander 2007, p. 19711);
- Aquaculture depends in large measure upon the availability and effective management of genetic resources for farmed aquatic plants and farmed fish, and also for those organisms that provide for the ecosystem services they need, in particular their food (Pullin 2007, p. 109).

2.4.2. Differential impact on food security

As Halpern *et al.* (2008) highlight, the impact intensity of different human activities on marine ecosystems is unevenly distributed across the seascape, and the composition of anthropogenic drivers is strongly dependent on local conditions. They show that climate change factors (ocean acidification, UV radiation, and especially changes in sea temperature) are cross-cutting factors, influencing by far the largest areas of both coastal and offshore habitats and being responsible for high *cumulative threats* on a global level (*ibid.*, p. 950 f.).

The fisheries sectors of Central and Northern Asian countries, of the Western Sahel and tropical South America are predicted to experience the highest impact of climate change (IPCC 2007b, p. 292). Studies on the *community and household levels* suggest that climate-related vulnerabilities on a local level are tied to broader poverty and human security issues, including insecure tenure and disrespect of common property rights (Kelly and Adger 2000).

The combination between climate change effects on marine biodiversity and human alteration of marine ecosystems by "fishing down the food webs" are especially threatening to the food security of *small-scale and artisanal fisheries*, as few fish are left over from industrialized fisheries in coastal areas. Decreases of fish resources are well documented for many African countries (Pauly *et al.* 2005, p. 9). For example, over-harvesting of fisheries resources and ocean bed damage from bottom trawling reduce the abundance and/or taxa of fish in marine ecosystems by 20-80 percent (Nellemann *et al.* 2008, p. 50).

For *freshwater fish*, the situation is no less disquieting. Xenopolous *et al.* (2005, p. 1562) have shown that potential freshwater fish extinctions that are related to reduced river discharge might be concentrated in species-rich tropical and subtropical areas that are also rich in endemic fish, like the Senegal, Tigris and Orinoco Rivers. Like with marine fisheries, scenarios show that "poorer countries, some of which rely substantially on indigenous fish for food […], are likely to be affected more from reduced discharge than richer countries." According to their findings, countries with decreasing discharge have a lower GDP and 18 percent more of their population below the *poverty* level than countries with increasing river discharge (*ibid.*, p. 1563).

In comparison with agricultural crop diversity, the *knowledge* about the genetic composition of fish populations, the state of breeding and the establishment of ex-situ collections and conservation techniques is generally less developed to date. It can be added that also the *legal status* of marine biodiversity, in particular in areas beyond national jurisdiction is less clear which may put an additional burden on coordinated international efforts for conservation (Kimball 2005).

3. Systemic and second order effects of climate change on biodiversity for food and agriculture

3.1. Combined and systemic effects

When single climate parameters change, effects on ecosystems, their biodiversity and associated services with regard to food security will not occur in isolation from other physical, social or political factors. Rather, multiple interrelations and cross-scale interactions can be expected, potentially intensifying the effects of single parameter changes and thus deepening their impact on food security. Interactions seem likely on three different dimensions:

1. Combinations of changes in key climate parameters may add up to build new, more intense threats to biodiversity for food and agriculture;
2. As food systems are composed of diverse sources of food production and availability, the impact of biodiversity loss in the different sectors of food production can accumulate and interact on different geographic levels (local,

regional, national, international)Changes in single sectors (agriculture, forestry, fisheries) can thereby add up to structural changes in the complex food system of aggregated social structures; finally

3. The physical climate change factors described above may combine with other anthropogenic stressors and socio-economic drivers that are either related to climate change *or not*, with potentially new and additional, wide-ranging effects on biodiversity for food and agriculture.

Regarding the *first dimension*, changes of climate parameters will often occur simultaneously, with complex interactions and effects on biodiversity in all food production sectors. Although these interactions can be difficult to predict by their very nature, some examples for *negative synergies* between different factors can already be observed:

- *Shifts of ecosystem boundaries,* as they have been described for all food production sectors, are usually the result of a combination of two or more changing parameters. For land-based ecosystems, shifts are particularly likely when rising temperatures coincide with changes in precipitation levels. Aquatic ecosystem shifts are triggered by changes in water temperature and currents;
- The positive effects of rising CO_2-levels on plant growth are counteracted by other climate change factors which seem to limit and, under more extreme conditions, overturn the 'carbon fertilization effect'. Thus rising temperatures and decreasing precipitation may not only lead to changes in ecosystem composition and corresponding ecosystem services for agriculture and livestock husbandry and forestry but also *offset expected benefits*;
- In marine ecosystems, interactions between different climate change parameters might generally change the *timing of different oceanographic events* and thereby affect the reproduction cycles of marine species. As a result, species composition and food webs within marine ecosystems may be altered;
- More generally speaking, *ecosystems* as basic units for all sectors of food production are likely to experience multifactorial climate change effects as different parameters develop cumulative effects. In many cases, this will have repercussions on wild and cultivated biodiversity for food and agriculture beyond particular types of organisms, as already weakened production systems are especially vulnerable to additional changes in environmental conditions. Thus, multifactorial 'background' climate change effects may pose more serious threats to biodiversity than direct effects on particular species, varieties or breeds, and thereby also lead to significant changes of ecosystem services;
- Loss of wild and largely uncultivated biodiversity may play an important part in such processes, as well as *genetic erosion* or impoverishment on sub-species levels. Both may increase food insecurity and reduce the adaptive capacity of particular food production systems;

Regarding the *second dimension*, livelihoods and food systems often depend on more than one sector of food production. Hence, apart from the direct threats caused by the changes in main climate parameters to specific crop production, livestock and fisheries systems, there are important *systemic effects* on livelihoods which themselves have potential repercussions on wild and cultivated biodiversity for food and agriculture:

- The direct and indirect effects on particular sectors of food production may systemically weaken or endanger existing livelihoods in their specific *spatial and functional arrangements* and thereby destabilise social settings and threaten food security (cf. Kasperson and Kasperson 2001).
- The impact of biodiversity loss in general, and the narrowing genetic bases of biodiversity for food and agriculture in particular, may also play out on *meso-scale levels* of aggregated households and communities, by diminishing the ability of more complex social systems to react to rising climate change pressures through functional differentiation and spatial compensation effects;
- On regional and national levels, decreasing crop and pasture yields will likely lead to growing pressure to extend food production in all sectors, which might include resource extraction from largely uncultivated ecosystems and areas hitherto used extensively. *Marginal lands* may be taken under cultivation and *unsuitable farming practices* be adopted to compensate climate-change induced food shortages; freshwater and marine fisheries might need to be extended, and forestry intensified. By increasing the pressure on all sectors of food production and by contributing to growing competition, decreasing plant performance might lead to further threats to both wild and domestic biodiversity in many ecosystems (IPCC 2007b, p. 294);
- Generally, positive food system outcomes on higher geographical levels tend to depend on a variety of resource pools, on the services of different and diverse ecosystems, and on interactive processes of food production, storage and exchange in and between different sectors. While such *complex regional settings* may provide for some buffering potential with regard to spatially limited breakdowns, they may be particularly vulnerable to combined and systemic effects as they seem likely to become the rule under conditions of continuing climate change. The corresponding loss of biological diversity and the multiple changes of ecosystem services may thus pose particular challenges for the livelihood strategies of individuals and social groups that are tied to such complex regional settings.

Regarding the *third dimension*, finally, biodiversity for food and agriculture is not only affected by mere physical changes in environmental conditions as described above, but is also threatened by a number of other anthropogenic stressors in most cases. Although climate change is gaining importance for biodiversity loss, it is to date still outmatched by some of the well-known other factors (e.g. land use change in agriculture, overfishing in marine ecosystems). Some of these factors are influenced or may be influenced by climate change processes themselves, while others are completely independent from changing climatic conditions:

- Linkages of climate change effects with *additional anthropogenic pressures* are particularly visible for marine biodiversity. Nellemann *et al.* (2008, p. 26) identify the ‘Big Five’ stressors to marine environment as climate change, pollution, fragmentation and habitat loss, invasive species infestations and over-harvesting from fisheries; the latter being considered the most serious single threat to biodiversity in marine ecosystems, with climate change effects adding on ecosystem damages derived from fisheries;
- Substantial changes of food production, especially in the plant-growing and livestock sector, are driven by a rising demand for milk, meat, eggs and other livestock foods which is largely due to *changing consumption patterns* and, more specifically, to growing human populations in the developing world in combination

with rising household incomes for substantial parts of respective populations (Steinfeld *et al.* 2006). The transition to industrialized modes of agricultural production that focus on very limited aspects of ‘output’ (such as kg corn or meat) directly endangers the biodiversity of agricultural crops and the survival of local livestock breeds alike. These developments may in themselves *increase competition* for agricultural and pastoral lands, the need for irrigation water, demand for fertilizers etc.;

- Additional factors like distribution of *plant and animal disease vectors* by intensified international trade may put further pressure on existing livelihoods, in particular for smallholders with limited capital and monetary assets;
- By weakening the agricultural work force, the expected spread of *human disease vectors*, i.a. for Malaria and Dengue fever will directly affect the coping capacities of rural and urban populations. This in itself has potentially strong effects on food security, particularly where social security systems are weak or absent;
- In a larger view, finally, land use conflicts, migration, *social disruption* and civil strife may ensue from systemic changes, with potentially most severe secondary consequences for food security (cf. Barnett and Adger 2007).

Cumulative and systemic threats to terrestrial and aquatic biota arise from simultaneous exposure of ecosystems and species to several stressors, leading to negative synergies between the single parameters and deepening their potential impact. The threats to biodiversity for food and agriculture in the face of multifactorial, combined effects of both physical and social factors on particular local and regional settings are difficult to predict, as they have to assume shifts and changes in all factors of production and on different spatial and temporal scales, thus meeting with extreme methodological difficulties. For this reason alone, the predictions that general socio-economic development will lead to just a marginal increase in the number of people at risk of hunger due to climate change only have a *limited level of confidence* (cf. IPCC 2007b, p. 275f.).

The given examples also show that agricultural and environmental *policies* will be important factors in determining the consequences climate change will have on biodiversity for food and agriculture. Berry *et al.* (2006) have shown in a European setting how the vulnerability of farmers to climate change can depend on policy interventions. Accordingly, with a growing need and willingness for political interventions with regard to issues of climate change, related policies will have to be treated as important factors and drivers of change in their own right. On regional and national levels, these policies might determine the extent of additional pressures on ecosystems and may have the potential to limit their impact on biodiversity and food security. This underlines the necessity to mainstreaming biodiversity concerns, not only into planning processes in the agricultural sector (CBD SBSTTA 2007, p. 41) but also to other sectoral policies.

The need for adaptation to climate change and mitigation measures to reduce global GHG emissions places even more responsibility on national and international climate and environmental policies. Adaptation and mitigation measures themselves have the potential to put pressure on agro-biodiversity. For example, an extension of cultivated areas for bio- and agrofuels (palm oil plantations, *Jatropha* etc.) may directly threaten wild ecosystems and their biodiversity, replace existing agricultural production zones and thereby further reduce suitable land for certain food crops or livestock (CBD 2008, p.4). Therefore, a brief look also at the potential effects of policy responses to climate change is needed.

3.2. Potential impact of mitigation and adaptation measures on biodiversity for food and agriculture

3.2.1. Potential impact of mitigation measures

The important contribution of agriculture and forestry to GHG emissions is well documented. Of global anthropogenic emissions in 2005, agriculture and land use change together made up for roughly a third of CO_2-emissions, and agriculture alone accounted for about 60 percent of nitrous oxide and half of methane emissions (IPCC 2007c, 499ff.). Accordingly, the *mitigation potential* of agriculture, forestry and land use change more generally speaking has been the subject of much research and debate over the last years (IPCC 2007c; Smith *et al.* 2008). Indeed, the scope and magnitude of measures that can be taken in this field are impressive and there is little doubt they have to be a key component in every integrated strategy to mitigate climate change. Accordingly, the stakes are also very high when it comes to the role of biodiversity in that context, and to questions of food security.

Smith *et al.* (2008, p. 790) differentiate the *options for mitigation* of green house gases in agriculture into three broad categories: the reduction of emissions by more efficient management of carbon and nitrogen flows; the enhancement of carbon removal by building or expanding ‘sinks’ in soils and agroforestry systems; and the avoidance or displacement of emissions as through agrofuels or efficient agricultural management practices. Among the measures currently discussed are cropland and grazing land management practices (improved nutrient management, low or zero tillage, agroforestry schemes, changed grazing intensity), organic soil management and restoration (avoided drainage, erosion control etc.); improved livestock management (feeding, breeding) and different forms of land-use change (including set-asides and agrofuel schemes) (*ibid.*, 791). Obviously, the range of options currently under discussion has very different potential effects on biodiversity for food and agriculture.

A number of these mitigation measures clearly have a *positive potential* also in terms of food security as well as for the conservation and sustainable use of biological diversity. This is the case for a number of cropland and grazing land management improvements, for organic soil management and for agroforestry schemes that are inherently linked to higher levels of diversity. Related measures can help to maintain, enhance and restore different kinds of ecosystem services at the same time and develop considerable synergies with food security and broader development goals.

Yet, recently, it was mostly the *threats* emanating from large-scale bio- or agrofuel schemes that have taken the attention of scholars, politicians and activists. Adverse effects on biodiversity and human well-being are expected, especially under certain production conditions:

> *“The increasing demand for bioenergy could lead to both direct and indirect expansions of cultivated areas, resulting in further habitat loss and negative impacts on biodiversity, especially if forest, grassland, peatland and wetlands are used for feedstock production and if large monoculture plantations are created. […] as biomass feedstocks can be produced most efficiently in tropical regions, there are strong economic incentives to replace natural ecosystems with high biodiversity values with energy crop plantations […]. If energy crop plantations are established on forested land or carbon rich soils any reduction achieved through the use of biofuels could be negated or even greatly out-weighed by the release of*

> *greenhouse gases stemming from land-use change and the production of feedstocks."* (CBD 2008, p. 4)

The conditions for a *sustainable production of agrofuels* are currently being explored and debated in different institutional settings (Fritsche *et al.* 2006, The Royal Society 2008, CBD 2008).

Meanwhile, comparably little systematic attention is directed to the *opportunities* for biodiversity enhancement inherent in any large-scale schemes for land use change, in particular afforestation and reforestation schemes. This might be especially interesting for afforestation and reforestation measures taken under Kyoto protocol's Clean Development Mechanisms (CDM). Opening up CDM-measures to agro-forestry or sylvo-pastoral schemes might clearly enhance the opportunities to include biodiversity conservation in general climate-change mechanisms. So far, there is a lack of clear and transparent standards, criteria and indicators with regard to the biodiversity component of such measures. This concerns the standards of (re-)plantation for the areas in question as well as the taking into account of different levels of pre-existing biodiversity in such areas. It has been argued, in a more general perspective, that the potential synergies between biodiversity conservation and climate change policies have hardly been explored so far (CBD 2003).

3.2.2. Potential impact of adaptation measures

The deliberate change of species or varietal composition in given food production systems can form part of the two main types of climate change adaptation measures that are commonly distinguished, i.e. autonomous and planned adaptation. *Autonomous adaptation* has been defined as the "ongoing implementation of existing knowledge and technology in response to the changes in climate experienced" (IPCC 2007b, p. 294) and is often conceived in terms of individuals' or small groups' reactions to changing conditions (cf. Reilly and Schimmelpfennig 1999). *Planned adaptation* on the other hand is the term to encompass more coordinated action on higher aggregation levels, or in the words of IPCC, "the increase in adaptive capacity by mobilising institutions and policies to establish or strengthen conditions favourable for effective adaptation and investment in new technologies and infrastructure." (*ibid.*)

Potential measures of adaptation to climate change in agriculture, forestry and fisheries thus include a whole range of changes in management (sowing and harvesting dates, irrigation, tillage methods, forest fire management, promotion of agroforestry etc.) including measures that directly relate to and make use of biological diversity. Crop selection and breeding strategies aiming at tolerance to abiotic and biotic stresses (temperature, drought, pest resistance etc.), the combined use of different varieties and genetically diverse populations and related efforts are seen as key components for adaptation (FAO 2007c, p. 9). While some of these *biodiversity-based adaptation measures* can be implemented readily on the level of individual farms or households, others need broader infrastructural and political support and have much longer time-frames.

Given the importance and potential of biodiversity for adaptation to climatic changes on local, regional and international levels, there is a recognized need to strengthen existing and build new international *initiatives in plant and animal breeding* that combine aims of food security with the needs of adaptation. At the same time, there are strong reasons to strengthen and expand efforts directed at collection and *ex-situ conservation* of genetic resources for food and agriculture as building blocks for current and future adaptation needs (*ibid.*).

There are several reasons why local *in-situ conservation* and *participatory plant breeding* initiatives should complement ex-situ collections and even be strengthened with a view to both, food security and climate change adaptation aims. From an ecological point of view alone, it seems difficult to re-establish complex multi-species and multi-variety production systems from selectively stored materials. From a systemic perspective on production systems including their social basis, the challenges will be insurmountable in many cases. The ability of the most vulnerable populations to retrieve and control components from the scientific-technical domain without targeted support can be assumed to be generally much lower than their inventiveness and general coping capacities in established, diverse production systems. Recent research has underlined in this context the *role of knowledge*, education and "adaptation memory" (Tschakert 2007).

Both autonomous and planned adaptation measures may also bear some risk regarding the conservation of biodiversity for food and agriculture. Possible *negative consequences* may arise from an extension of production zones as a reaction to decreasing yields, from adopting unsuitable cultivation methods and, generally, from unsustainable modes of food production in order to compensate for production losses in the different sectors. Planned adaptation may also entail a re-allocation of financial resources and the prioritization of measures that run counter to biodiversity conservation efforts (e.g. large-scale flood protection schemes).

4. Conclusion: Taking second order effects into account

Research on climate change impact has so far largely focussed on the direct effects caused by changes in key climate parameters such as mean temperatures, levels of precipitation, likelihood of extreme weather events, rising sea levels etc. The main changes in these factors are today well established and scientific projections for the coming decades widely accepted. Many of the predicted shifts and changes will directly impact food production systems, in fisheries, forestry and agriculture including agro-pastoral systems. Yet, as discussed above, in the context of food security and with regard to the particular role of biological diversity, indirect and complex *systemic effects* may be even more important in many cases.

As stated above, the result of combined and systemic effects on particular local and regional settings and their overall outcome in terms of food security are far from clear. They pose an immense *challenge to research* and are difficult to predict for their methodological complexity, stemming i.a. from linkages between sectors and across scales in time and space. As a result, predictions that the increase in the number of people at risk of hunger due to climate change will be limited thanks to broader socio-economic developments (IPCC 2007b, p. 275f.) are fraught with considerable uncertainty also on a global level.

Meanwhile there can be little doubt – and there is growing, if still scattered evidence already – that biological diversity, both wild and cultivated, will be (additionally) threatened in many ways by the upcoming biophysical changes. This regards freshwater and marine diversity and terrestrial diversity alike, and it spans from the loss of genetic diversity properly speaking to the loss of species and whole ecosystems. Accordingly, the different types of *ecosystem services* are also threatened, affecting not only provisioning services directly related to food production, but also regulating services like biological pest control, supporting services like nutrient and water cycling, and the cultural services that are intimately tied to the existence of particular species or ecosystems (MEA 2005a).

At the same time, there is large agreement that biological diversity for food and agriculture also has a growing role to play in the autonomous and planned *adaptation* to climatic change. *Genetic diversity* available in particular food production systems can be directly related to their adaptability on local and regional levels, and thus to the coping capacities of individual farmers and households under multiple stresses. It is a key resource also for higher-level strategies of national and international agricultural development. Both, *in-situ* and *ex-situ* strategies for the conservation and evaluation of genetic resources should therefore be strengthened. Furthermore, the particular risks of climate-related changes must be assessed in the fisheries, forestry and agricultural contexts, for particular regions, and also for particular food productions systems. With a higher spatial resolution and growing reliability of climate change scenarios that are underway, substantial progress can be expected with regard to these questions over the next years.

To assess and *strengthen the adaptive capacity of vulnerable groups* in general, and particular food productions systems, however, it will be largely insufficient to provide technical assistance, develop new varieties or breeds, and conserve biological diversity in gene-banks and set-asides. Such classical modernizing approaches are not only mistaking the socio-political architecture of today’s conflicts over biodiversity (cf. Flitner and Heins 2002). There are a number of specific reasons why they are *inadequate* also in practical terms:

- On a *scientific and technical level*, there are large differences between the different realms of biological diversity with regard to the knowledge and state of the art of breeding and conservation options. E.g. whereas ex-situ collections for major staple crops are substantial and preservation techniques well established, this is much less the case for animal breeds, and even less for capture fisheries (see ch. 2, above);

- On a *conceptual level*, there is no reliable, quasi-automatic link between the adaptive capacity (or ‘resilience’) of particular social-ecological systems and the biological diversity on different levels contained within them. What may apply and seems largely accepted as a general rule – more diversity, higher adaptability – may dwindle in the face of specifically combined new threats (e.g. ocean acidification and changing currents for marine biodiversity; extreme weather events and mean temperature changes outpacing genetic drift potentials for forest biodiversity); in some cases, ‘modern’, high-input monocultures maybe more readily transformed, shifted or replaced than complex, place- and culture-bound polycultures;

- In the *social dimension*, the inherent focus on production is in itself insufficient to tackle the problem of food security which is equally based on storage, processing, distribution, exchange, preparation and consumption of food, and according entitlements (see ch. 1.1., above);

- *Broader socio-economic developments* in and beyond the sphere of food production, like changing consumption patterns in large parts of the world, will continue to be important drivers of land use change over the coming decades. They will lead to further changes in global food markets, induce new competition over land and labor, thus influencing and interacting with other drivers of change, often in a non-linear fashion.

Against this background, and maybe most importantly, the *responses to climate change* are very likely to constitute in themselves important additional drivers of change, on a secondary level. The current and planned measures to react to climate change have an outstanding potential to influence the further development of biological diversity and food security, and the links between them. This has recently become most visible and debated with regard to the development of agrofuels based on food crops like soybean, corn, sugar cane and oil palm plantations (see ch. 3.2., above). But it will certainly put its mark beyond the field of agroenergy, by influencing the plans for large-scale re- and afforestation, by new priorities for freshwater distribution, by new financial needs for hazard control and disaster management, by shifts between production regions for specific crops or breeds, and, last not least, by changing perceptions and media coverage.

These *second order effects* are to a large extent *policy-driven* and they can already be observed. They are ranging from new agricultural subsidy schemes and changing priorities of international organizations over the research budget allocations of national ministries and academic departments down to the production decisions of many farmers and companies around the world. Their impact on land use change and food security may already be comparable, and in the mid-term even bigger, on a global level, than that of expected changes in main climate parameters such as mean temperatures or precipitation patterns. This possibility should be duly taken into account by adaptation planners in donor organizations and national as well as international policy bodies.

Apart from the risks associated with this development, there is clearly also a range of *second order opportunities* to combine biodiversity related policies, programmes and projects with climate change adaptation and mitigation measures. Relevant instruments include payment schemes for agro-environmental services or certification of sustainable forestry and fisheries practices. To be sure, synergies with broader development goals, and with the aim of *food security* in particular, will not always be reached without additional effort. But it has been shown that such synergy can be achieved in many instances, with regard to forest-, as well as agriculture- and fisheries-based livelihoods (Klooster and Masera 2000; Sanchez 2000; Kelly and Adger 2000; on a conceptual level *see* Halsnæs and Verhagen 2007). Other than for farmers, individual households or communities, the *challenge for national and international bodies* with regard to biodiversity for food and agriculture is then not to focus on technical and practical adaptation and conservation needs resulting from changes in the main climate parameters, nor on sectoral improvements in production. Rather, it is to address the second order, largely policy-related effects in an adequate manner so as to minimize their inherent risks for the most vulnerable groups and make the best use of the opportunities that are opening up, in particular in the expected dynamics of land use change.

To sum up, the impact of climate change on biodiversity for food and agriculture will not be a simple function of quasi-natural drivers and pre-existing social settings. Agricultural and environmental *policies* in the widest sense will be an important factor with more than just a mediating role, influencing the available options of vulnerable groups in rural and urban settings alike. Land use planning, issues of tenure and access, and financial incentives for particular products, production systems or environmental services are among the most obvious dimensions affected.

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