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CLIMATE CHANGE–INDUCED WATER STRESS AND ITS IMPACT ON NATURAL AND MANAGED ECOSYSTEMS

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EXECUTIVE SUMMARY

Climate change and water resources

Climate change will affect water availability differently in Europe – likely a large decrease in Southern Europe, while an increase in the North. However, the largest increases will be felt where very few people actually live – above 60°N, whereas large populations will be affected by shortages. Indeed, if climate change can be thought of as another 'consumer' of water, in some countries it will be a larger consumer than current domestic, industrial and agricultural uses combined.

Decreases in glacier ice volumes is affecting *runoff* into rivers in central Europe – only about one third of the ice volume present in the mid-1800s still remained in 2006.

Even where there are likely to be annual increases in precipitation, it may not fall at convenient times for *agriculture* – likely higher in winter and falling during the growing season.

While the *drought* of 2003 caused around €13 billion in damages and was exceptionally bad, it is not necessarily indicative of a recognisable trend, given natural variability, but is consistent with predictions for the future given climate change.

The annual number of reported *flood disasters* in Europe increased considerably in 1973-2002. It is likely that land use change, river channel modifications and increased activities in areas vulnerable to floods are probably the most important influences on flooding today. In future there will likely be an increase in flash floods due to heavy precipitation, including in major rivers; coastal flooding will also increase due to more intense storms and sea level rise.

With respect to *water quality*, most climate change impacts can be attributed to changes either in discharge or in water temperature. To a minor degree climate change may also affect the levels of direct atmospheric input of nutrients and other elements to surface waters.

Agricultural impacts

Agriculture also belongs to the main water users in Europe, using ca. 38% of the total abstracted water. Most irrigation is concentrated in Southern Europe, while rain-fed agriculture is common elsewhere. Both will be affected by climate change, as there will be an increase in irrigation demand at a time when water will in many places be less available.

Livestock production may also be affected: heat stress may increase the mortality of animals, while droughts may reduce the productivity of grasslands such that they are no longer sufficient for livestock.

Higher precipitation in the northern latitudes of Europe, combined with an increase in temperature, may prolong vegetation periods, increasing crop yields. However, rises in certain plant diseases and pests, and an increase in the frequency and intensity of extreme weather events will be damaging.

Industrial impacts

Hydropower may benefit from increased hydropower potential in Nordic countries, but in Southern and South-eastern European countries can expect reductions of 25% or more of hydropower potentials due to reduced river runoff. Thermal power stations may be affected by increases in water temperature (restricting cooling water discharge into rivers) and water scarcity (reducing cooling water availability). Biomass production will vary as with agriculture – benefiting somewhat from higher temperatures and CO_2 concentrations, but hurt by water scarcity, drought, floods, extreme weather and pests. Energy infrastructure may also be at risk of damage from severe weather and sea level rise. Finally, energy demand in winter will probably decrease, and rise in summer – however, with greater extremes of heat and water scarcity during peak periods it will be overall more challenging to meet energy demands.

Transport

Climate change may affect the transport sector mainly through infrastructure damage, and through effects on the navigability of waterways. The likely increase in extreme weather events, but also the increase in temperatures, may cause damage to transport infrastructure or affect road and rail safety. In particular, flooding of underground rail systems and roads with inadequate drainage may be a problem.

Human health

Climate change impacts may significantly affect human health by a variety of stressors. Increased temperatures are predicted to cause more (predominantly cardiorespiratory) deaths and illness, cold related deaths on the other hand are likely to decline with milder winters. Health impacts related to water arise mainly from more frequent storms and floods. In combination with higher temperatures water may also provide the routes for spreading of new diseases.

Potential conflicts over water

Potential political conflict over water under a scenario of climate change is most likely to arise from water shortages. The demand for water by different sectors such as agriculture, tourism, electricity and households is likely to increase precisely during the times when there is likely to be the greatest water stress. Other conceivable causes could be conflicting policies, such as the increase in energy crops relying on water; or an increase in flood events in transboundary river systems.

Cross-border water management principles

Cross-border water management will play an important role in adapting to increased flood and drought events. Many rivers in Europe face quality and flooding problems, or water scarcity and allocation problems, and both can be exacerbated by climate change impacts. Thus, integrated management of water resources across national and administrative borders will become even more important under a changing climate. Several countries sharing a transboundary river basin already have according management plans in place, and cross-boundary co-ordination in international river basins is strengthened by European legislation (Water Framework Directive). One prominent example is the co-operation between Portugal and Spain who share four principal rivers: the Miño/Minho, the Duero/Douro, the Tajo/Tejo, and the Guadiana.

Adaptation policy approaches

While adaptation will to a large extent occur at decentralised levels, adaptation measures being implemented locally and regionally, a strong role for governments and for policy-driven adaptation is nevertheless recognised widely. Government action can contribute to motivating early adaptation and to supporting efforts by private actors. A need for policy action is identified for instance with regard to research, information and communication, regulation and standards, public infrastructure, early warning and disaster relief, regulating the distributional impacts of adaptation, and embedding adaptation in sectoral policies.

Policy approaches at European level

Adaptation to water-related climate change impacts is gaining relevance both on the political and the research agenda in Europe. The most important policy initiatives bearing directly on the issue today are the Green Paper on adaptation, the Water Framework Directive, the Communication on water scarcity and droughts, the Marine Strategy Directive, and the EU Directive on flood risk and management. Other policy areas are also highly influential, such as the Common Agricultural Policy and EU cohesion policy. At the international level, adaptation is an important issue in international policy activities, for instance under the United Nations Framework Convention on Climate Change (UNFCCC), and in bilateral and multilateral development co-operation activities.

Impacts on land and soil

Climate change and related water stress are having, and will in future continue to have, impacts on land and soil around the world, including in Europe. The rural environment, meaning natural habitats, agricultural land and forests is under a variety of pressure, much of it anthropogenic, which is magnified by climate change stress.

Climate change and associated changes in water regimes are predicted to be particularly damaging to natural ecosystems, which are already under tremendous pressure from human land use requirements, pollution, and resource exploitation and are thus degraded and vulnerable to begin with.

Natural Ecosystems

Deserts face conflicting influences under climate change: potentially seeing more vegetation with higher CO_2 levels, but overall facing increases in drought and warmer temperatures. As ecosystems in deserts are already in a fragile environment, impacts could be severe.

Grasslands are influenced by precipitation – even where increased, seasonal variability is important, and declining summer rainfall could be damage grassland fauna.

Mediterranean ecosystems are diverse and vulnerable, susceptible to changes in water conditions. Even in the range of 2 degree warming, 60-80% of species may be lost in the Southern Mediterranean, while the Cape Fynbos in South Africa may lose 65% of its species.

Tundra/arctic: with greater warming at the poles, the loss of permafrost and the potential for methane release is a major concern.

Mountains are seeing shortened and earlier snow and ice melt and related changes in flooding. At higher altitudes, increased winter snow can lead to the opposite problem of delayed snow melt.

Wetlands will be negatively affected where there is decreasing water volume, higher temperatures and higher-intensity rainfall.

Crops and grazing land

Around 40% of the world's land surface is used for crops and grazing land. Some 80% of the world's agricultural land is rain-fed, and nearly all pasture land. About a third of the world's land area is already too dry for rain-fed agriculture, and less than 2% of that amount is suited to cereal crops under irrigation. Therefore, the effect of precipitation changes on agriculture and grazing are of utmost importance to consider. Models show that in general, high latitudes and the wet tropics might see increased runoff, with decreases elsewhere. Some areas currently rain-fed would slip into the category of unsuitable – including the Mediterranean basin. Meanwhile, precipitation extremes (including more severe periodic rainfall) are expected in much of Northern Europe.

All agricultural systems across Europe are likely to be affected, at least to some extent, by the projected changes in climate in the coming decades. There may be positive effects on agricultural production in some regions over the coming decades, where rises in CO_2 promote production in crops such as wheat, barley, rye, potato and rice. As climate change advances, however, its negative impacts, such as more frequent winter floods, are likely to outweigh these benefits. Farming systems in southern Europe will be most vulnerable to climate change due to rising temperatures coupled with decreases in both summer and winter rainfall in areas already experiencing water scarcity.

The management of land and soils and their associated ecosystems are inextricably linked to the provision and overall availability of water resources, both groundwater and surface waters. Indeed, water availability is likely to become the major driver of future land use, potentially precipitating significant land-use changes over the coming decades.

Ways of improving the capacity of the land to *deal with water scarcity* include maintenance of vegetative cover, preferably with native species suited to the local conditions; coverage of steeply sloping land should be prioritised in order minimise surface runoff and prevent soils from drying out; and greater water conservation measures, water pricing, reducing leakages from water supply networks, and effective controls on water abstractions and subsequent water use.

Natural ecosystem adaptation is also possible, such as maintaining and enhancing the capacity of mountainous regions to capture rainfall effectively, limit soil erosion, and regulate water flow; improving grassland management, such as making adjustments to the cutting and grazing regimes; and avoiding drainage and conversion of wetlands and peatland.

Options in agriculture include efficiency improvements to irrigation management, conservation tillage, establishing native varieties to permit regeneration, water conservation, changing crop types and introducing new types of crops. In theory, many of the impacts on the productive capacity of the agricultural sector can be addressed. However, some of the more extreme measures would precipitate changes to land use and structural changes, both in terms of the landscape and farming systems.

Aside from requiring adaptation, agriculture also offers *opportunities to mitigate* emissions of greenhouse gases, among these are increasing soil carbon, including through the maintenance or re-flooding of peatland; and the use of bioenergy crops. Bioenergy crops can be used for electricity, heat and liquid or gaseous fuels. While the potential for mitigation is relatively large, there will need to be attention to the issues of land use and biodiversity to avoid unintended negative consequences.

Given its capacity to affect practices at a European scale, the Common Agricultural Policy (CAP) is an obvious policy to address in terms of climate change. The response to climate change in the rural environment, and the exploitation of mitigation options, does not need to be a remodelling of the CAP. A series of specific and targeted measures, informed by a land use and environmental perspectives and supported by an adequate budget, would respond to new and sometimes unpredictable requirements. Links between farming, energy and environmental policy perspectives need to be strengthened and institutional relationships adjusted accordingly.

Forests, Deforestation and Climate Change

Emissions from deforestation alone are estimated to account for 25% of all the anthropogenic greenhouse gas (GHG) emissions. Since causes of deforestation and land use change are very complex, current mechanisms to combat the loss of forests have mostly failed. Instead, forest degradation worldwide is continuing, additionally driven by growing demand for food due to population growth and changing consumption patterns in emerging economies as well as increased use of biomass for bioenergy.

Forests provide a range of ecosystem services which are generally underestimated, or left out of estimates altogether. In terms their relationship with climate, forests play a major role in climate mitigation strategies through carbon sequestration and the provision of products substituting fossil energy and materials. Furthermore, forests contribute significantly to regional climate regulation and to continuous water supply in large and small scale water cycles. These regulating services of forests including their alleviating functions can be essential for adaptation strategies to climate change effects.

Carbon Storage

As one of the biggest natural carbon storage capacities, forest ecosystems function as an important carbon sink in the global carbon cycle – including absorbing an estimated 30% of the carbon emitted by fossil fuels. Keeping them intact is thus important, particularly in the tropics. There is a general trend of decreasing carbon stocks in forest biomass world wide; between 1990 and 2005 this was mainly driven by South and Southeast Asia (33% decrease), Western and Central Africa (7%) and South America (6%) while carbon in biomass remained approximately constant in Oceania and increased in Europe and in North and Central America in the same time span.

Fuel and industry

Forests also provide an important energy source: some 10-15% of world energy use. Further, without wood products, we would be using other, more GHG intensive materials not only for energy production like mineral oil but also for building and construction, since wood can substantially replace steel, concrete, glass, and aluminium. To an increasing extent wood is also considered to be an important resource for liquid biofuels. The degree to which sustainable forest management is applied will be crucial on how big gains in GHG savings are in comparison to other products.

Microclimate regulation

Forest cover basically influences all variables of regional climate: solar radiation, air and soil temperature, rainfall, air humidity and wind. In general, forest cover buffers the daily and seasonal temperature differences compared to open ground and notably the clearfelling areas, thereby alleviating microclimatic extremes. The shelter characteristics of forests protect from frost in winter and have a cooling effect in summer.

Water cycles

Forests modulate water flows in various ways that can differ significantly among regional conditions and forest types. Forest floors, with their leaf litter and porous soils, easily accommodate intense rainfall. Water infiltrates the ground until soils are saturated.

The "sponge effect" of forest ecosystems makes overland runoffs smaller and runoff timing longer compared to other land surfaces. Consequently, forests strongly contribute to the flood prevention when rainfalls are heavy. The filtration functions of forests are important also for water quality. Water running off from forested hills is far cleaner due to slower infiltration processes than fast run-offs from pastures or agricultural land. Trees also pump huge amounts of water into the air through evapo-transpiration, which tends to fall as precipitation nearby, which is important in otherwise dry areas.

All of the functions described show the crucial role forests have for stable climatic conditions. Intact forest ecosystems with their buffering functions (e.g. cooling effects, water storage and wind shield) can contribute significantly to adapting to biophysical changes induced by climatic change such as floods, droughts and temperature increase. Hence, synergies can be generated between forest management and adaptation strategies to climate change.

Deforestation and degradation

For the period 2000–2005 the total net change in forest area in the period is estimated at -7.3 million hectares per year, equivalent to a loss of 200 km^2 of forest per day. These numbers show that overall deforestation rates have slightly decreased in the recent years.

The causes are various, a wide range of economic, political and social issues, and often case-specific. Since deforestation and forest degradation are often side effects of non-forest policies, there is a big overlap to other policy fields that have to be taken into account. However, three main processes can be identified on the global level: shifts in agrarian activities, unsustainable practices leading to overexploitation, and increase in demand for commodities.

Without additional economic incentives, forest owners or future forest claimants balancing profit expectations will often opt for land clearings unless forests contain precious woods, many saleable trees, fast-growing trees, or if soils are unsuited to agriculture. Large scale deforestation is mostly made by enterprises with sufficient capital while smallholders can rarely afford deforestation because of financial and technological constraints.

Institutional factors also play a role, with drivers including incentives given by national policy, low levels of governance and law enforcement, and insecure property rights.

In all forest biomes, far fewer intact larger blocks of primary forests now with the existing small forest fragments retaining only a small portion of the normal species complement. The remaining forest systems also tend to be degraded or replaced by secondary vegetation further affecting the level of forest biodiversity. Thus, it is clear that forest biological diversity is rapidly declining due to deforestation and degradation of forest ecosystems, especially in the tropics.

The *impacts of deforestation and degradation* are various:

Deforestation results in a decline in overall carbon storage function of forests. It also increases atmospheric carbon levels by releasing carbon stored in biomass and as soil carbon, i.e. carbon in living and decaying matter locked in forest soils. Consequently, deforestation and land conversion have been significant sources of greenhouse-gas emissions for decades.

Deforestation also effects the ability of forests to regulate local and regional climate by decreasing evapotranspiration, resulting in warming of soil surface. This inhibits convection and causes decrease in the formation of cloud cover and precipitation

Decrease in forest cover may increase the scale of flooding on at local scale. Consequently, there is evidence that at local scale forests and forest soils are capable of reducing runoff. However, it seems that forests have only a limited influence on major downstream flooding at the basin level.

Deforestation and forest harvesting have been observed to increase nitrate, sea salt and suspended solid levels in stream systems. It has also been noted that forests have the capacity to capture pollutants with atmospheric origin.

Deforestation and changes in forest species composition and structure can also increase the risk of forests fires, e.g. by planting monocultures and/or increasing biomass of grass vegetation.

Other impacts can include loss of soil quality, slope stability and even disease control – such as through controlling the distribution patterns of malarial mosquitoes.

Socioeconomic impacts

Deforestation and degradation have direct economic impacts through loss of ecosystem services, and through the need to protect against the loss. In Portugal, direct losses from forest fires in the last 25 years have been about €300 million per year, while fire fighting and prevention has cost €479 million. The contribution of forests to water quality is estimated at €500 million per year in Bavaria, while the total value of the woodland ecosystem services in Great Britain is estimated to be €42,924 million: figures that indicate what could be lost due to deforestation. Where clear-cutting does take place, the economic advantage is both short-lived and benefits a narrow group of people.

Policy responses

The causes of deforestation are multiple, complex and region-specific. In order to be effective in the long term, policy approaches to reduce the loss of forests have to adequately address these interrelated drivers of deforestation. Approaches can include protection of property rights, and land-use planning; reducing illegal logging through better enforcement; economic incentives for standing forests; certification; ecotourism and non-timber forest products; payment for ecosystem services schemes; and finally inclusion of appropriate policies in international agreements like the UNFCCC.

1 CLIMATE CHANGE AND WATER RESOURCES

1.1 Scientific evidence on climate change impacts on water

If climate change is projected to decrease the water resources of a country, we can consider climate change as 'a new sector of water consumption'. This is particularly true, if human activities are responsible for climate change. There is widespread evidence that this is the case (e.g. IPCC, 2007).

Table 1 shows the internal water resources and present water use in some European countries. In the last column, one estimate for the consumption of water by climate change is in 2070 is given. In four of the six countries, the climatic water consumption is larger than the total water use today. These countries are France, Spain, Greece and Turkey. In the other two – Italy and Ukraine – climate change will consume “only” slightly over half of today's water use.

Table 1: Internal water resources and present water uses in some countries (data from various sources). The “consumption” of water by climate change is based on Echam4-model (cf. Figure 1; Alcamo et al., 2007).

Country	**Internal water resources (km^3/a)**	**Total water use at present (%)**	**Use in different sectors (km^3/a)**			
			Domestic at present	Industry at present	Agri-culture at present	Climate change in 2070
France	178	20	5.8	24.8	5.4	44
Spain	110	33	4.3	9.4	22.3	43
Italy	159	37	8.3	16.2	34.8	32
Greece	58	21	1.0	3.5	7.5	18
Ukraine	53	49	4.7	13.5	7.8	15
Turkey	196	17	2.8	2.0	28.8	47

The amounts of water resources deprived by climate change in Table 1 were based on Echam4-scenario. If HADCM3-scenario had been used (cf. Figure 1), the losses would have roughly halved in Spain, Italy, Greece and Turkey, decreased to one third in Ukraine and to almost zero in France[1]. The range of uncertainty in modelling future runoff in southern Europe (south of 47°N) is still considerable; according to Alcamo & al (2007) the decrease is projected to be 0-23% by the 2020s and 6-36% by the 2070s.

In northern and central Europe, climate change will be a new water source. Alcamo et al. (2007) give the range of runoff increase north of 47°N as approximately 5-15% by the 2020s and 9-22% by the 2070s. North of 60°N, these ranges would be considerably higher, particularly in Finland and northern Russia.

[1] ECHAM4 and HADCM3 are two state-of-the-art climate models widely used for climate change studies in Europe. They were developed by the Hadley Centre, UK (HADCM3) and the Max-Plank-Institute for Meteorology, Germany (ECHAM4).

Climate change is thus going to make the distribution of water resources in Europe much more uneven than it is today. And even today's distribution is highly uneven, particularly considering the distribution of population density. Almost 20% of water resources are north of 60°N, while only 2% of people live there.

Not only will climate change affect the spatial distribution of water resources, but also their distribution in time. In northern Europe, the flows in winter (December to February) will increase two- to three-fold, while in spring they will attenuate considerably, in summer increase slightly and in autumn almost double by the period 2071-2100. Considerably higher winter flows are also projected e.g. for the Volga, the Rhine and many smaller rivers in central and eastern Europe (Oltchev et al., 2002; Eisenreich et al., 2005). Summer low flow may decrease by up to 50% in central Europe (Eckhardt and Ulbrich, 2003), and by up to 80% in some rivers in southern Europe (Santos et al, 2002).

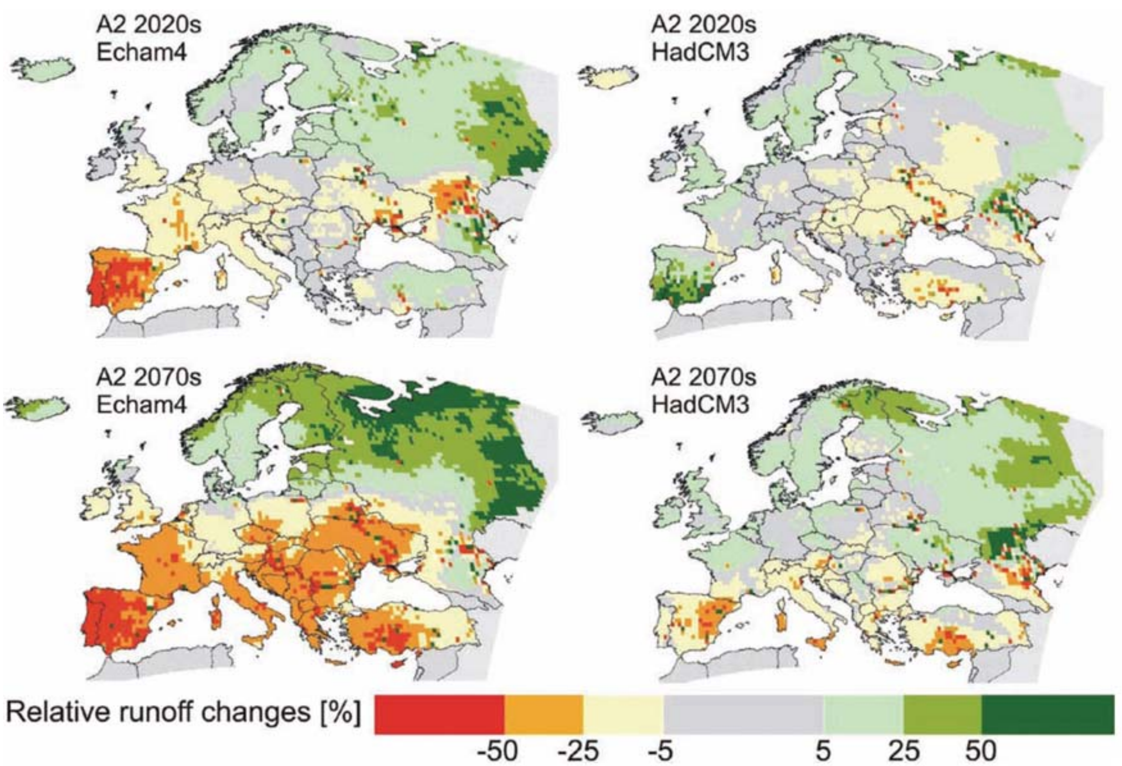

Figure 1: Change in annual river runoff between the 1961-1990 baseline period and two future time slices (2020s and 2070s) for the A2 scenarios (IPCC, 2007; Alcamo et al., 2007).

Several major rivers in central Europe are fed by meltwater from glaciers. In the mid-1800s, the total volume of ice in the European Alps was around 200 km^3. One half of this storage was left in 1973 and only one third in 2006 (Schaedler and Weingartner, 2007). This has led to additional summer flows, which is still likely to continue, but a significant reduction, up to 50%, will occur in the coming decades (Zierl and Bugmann, 2005).

The effect of climate change on groundwater recharge is inadequately known in many areas in Europe. Many factors affect this phenomenon: alterations in precipitation, evaporation and temperature regimes, soil properties and their changes, coastal flooding, urbanization, and changes in forest management and agricultural practices.

For the same region, both increases and decreases in recharge are possible. E.g. in Denmark, an enhanced recharge has been projected for sandy soils in Jylland, while a reduction would occur on Sjaelland with low permeability, clay soils (van Roosmalen et al., 2007). In some areas, the vegetation response to climate change would cause the average recharge to decrease, but in other areas, recharge would more than double. More research is certainly needed in this important topic.

From a human point of view, the changes in green water availability are also important, in addition to changes in blue water resources.[2] In most countries in Europe, green water is responsible for a much larger share of agricultural production than blue water, i.e. irrigation. Substantial decreases of precipitation in the growing season may occur in southern and central Europe, and they are possible even in northern Europe, despite of a considerable increase of mean annual precipitation. Particularly vulnerable are those countries, where rain-fed crop production plays a major role in economy. These include e.g. Ukraine and Balkan countries; the demand for irrigation may substantially increase in the coming decades.

1.1.1 Droughts

Droughts are a natural climatic and hydrological feature in Europe. They may occur recurrently in almost all European precipitation regimes, and in any season. They may have a rather limited areal extent or cover large regions over the continent. They may be short and intense, particularly in connection with heat waves, or they may develop slowly and persist for years.

The drought of 2003 caused a total economic cost of over €13 billion in around twenty European countries, affecting also biodiversity and the carbon balance. Billion-scale damages were also caused e.g. by the drought in Western Europe in 1976-77, in Iberian Peninsula in 1981-82 and most of the Mediterranean Region in 1988-91. The repetition of a 25 year spell of abnormally low precipitation beginning in the 1880s would have devastating consequences to water management throughout much of today's Europe. In the millennial time scale, even more serious droughts have occurred (Eisenreich et al. 2005).

There is no clear evidence that a widespread change in droughts has occurred in Europe over the last century or over the last decades (van Lanen et al. 2007). This statement is based on a large number of studies, some of which have had an extensive coverage in space and time. E.g. Pekarova et al. (2006) analysed 18 major European river basins over the period 1850-1997, neither significant long-term decreases or increased were detected. Hisdal et al. (2001) had a similar main conclusion for the period 1962-2000, although they found some regional trends: more severe droughts in Spain, United Kingdom and the western part of eastern Europe, less severe in large parts of central Europe. They also pointed out that subperiods with trends to both directions can be found in several regions from the data covering the whole 20th century.

[2] "Blue water" refers to water in rivers, lakes, reservoirs, ponds and aquifers that can be used directly by human activities, e.g. irrigation, hydropower, navigation, etc. The term "green water" is defined as the fraction of water that is evapotranspirated. Green water comes from rainfall and constitutes the water supply for all non-irrigated vegetation. It is stored in soils and ecosystems.

The areas with increasing drought risk in the future will mainly be comparable to those with decreasing annual flows in Figure 1. The Mediterranean countries will be particularly vulnerable, like some parts of central and eastern Europe. In a short time scale – up to a few months – heat waves may amplify the effects of droughts both to nature and human life.

The presence of different storages in the river basin may deflect the severity of drought from the regional pattern. Lakes, bogs and large groundwater aquifers can augment low flows considerably. On the other hand, depletion of cryospheric storages will have the opposite impact, as discussed above in connection to alpine glaciers.

A shift in climate can also create new transitional zones with unknown feedback mechanisms. This may be the case with the summer climate in central and eastern Europe due to strong land-atmosphere coupling, leading to an enhanced risk of droughts and heat-waves (van Lanen et al, 2007).

How long do we have to monitor climate in order to detect significant changes in drought characteristics, considering the large natural variability? Sheffield and Wood (2007) found that even in the Mediterranean region this will still take 3-4 decades, although the projected changes are major. There are also large uncertainties in the projections due to drivers like vegetation dynamics, land use changes and wildfires. Even the straightforwardness of meteorological drivers can be questioned, because there are complex interactions between temperature, precipitation, evaporation and hydrologic processes at the ground surface.

1.1.2 Floods

There are currently four major types of floods in Europe:

1. Floods following prolonged saturation during the wet season. These occur typically in winter in western Europe and in summer in parts of eastern and central Europe.
2. Floods following snowmelt in spring. The timing of their peak varies from February until June, depending on latitude and elevation.
3. Floods following short duration intense rainfall events. Most of them occur in summer. In urban areas they can cause considerable material damage, in narrow valleys in the countryside they can be very dangerous to human life (flash floods).
4. Coastal floods. They are due to rapid sea level rise and storm surges.

The annual number of reported flood disasters in Europe increased considerably in 1973-2002 (Hoyois and Guha-Sapir, 2003). **A disaster was defined here as causing the death of at least ten people, or affecting seriously at least 100 people, or requiring immediate emergency assistance**. The reported damages also increased. Three countries had damages in excess of €10 billion (Italy, Spain, Germany), three in excess of 5 billion (United Kingdom, Poland, France). The total number of reported victims was 2626 during the whole period, the most deadly floods occurred in Spain in 1973 (272 victims), in Italy in 1998 (147 victims) and in Russia in 1993 (125 victims).

The reasons for this development cannot be unambiguously explained. Hydrological data series do not indicate clear upward trends in the frequency and magnitude of floods in Europe, although some signals to this direction have been detected (e.g. Eisenreich et al., 2005). Floods have a multitude of causes, both meteorological and anthropogenic. Some increase of mean precipitation has occurred, but changes in the persistence of cyclones or the shift in their trajectories, which could affect type 1 floods, have not been proven.

The same applies to intense short-duration precipitation, responsible for type 3. Maximum water equivalents of snow cover have decreased in large areas, and type 2 floods consequently show some decline in their mean values, but not in their extremes. Cyclone density, deepening rate, central pressure gradient and translation speed have increased in North Atlantic in winter (IPCC 2007), having potentially worsened type 4 floods.

The direct anthropogenic causes include land use change, river channel modifications and increased activities in areas vulnerable to floods. There has been unfavourable development in all these factors in many areas in Europe. Natural flood retention areas have been reclaimed to human use, thousands of square kilometres of impermeable surfaces have been created, coastal urbanization has been extensive. The overall impact of these changes probably exceeds the impact of trends in meteorological variables in today's Europe.

A large number of projections of future floods in Europe has been presented. In the green paper on adaptation, the European Commission (2007) has presented a projection for the period 2071-2100 for catchments larger than 1000 km^2, based on one emission scenario SRES A2 and HIRHAM climate model. The general feature is a decrease of extreme flows in areas where snowmelt floods are dominating in the present climate. The hundred year floods will attenuate by 10-50% in northern Russia, Finland and most mountainous catchments throughout Europe. An increase by similar amount is projected in large areas elsewhere, whereas a mixed pattern is likely in Sweden, Germany and the Iberian Peninsula.

The results of many other studies share the general features of this projection. However, variations in the magnitude of change or even in its direction are common in relatively large areas. For example in Finland, an increase of floods is projected in several scenarios for the southern and central parts of the country. Thus the future is still rather uncertain in many regions.

Growing frequency and intensity of flash flood events is the likely consequence of heavier rains in small catchments even in areas, where floods in larger rivers are projected to increase. From the point of flood protection and coping strategies, this may be a great challenge. The same applies to coastal floods; more intense storms are likely and mean sea level will increase.

1.1.3 Water quality

Climate change will affect water quality in at least five ways (Arnell, 1998):

- a rise in water temperature will affect the rate of operation of biogeochemical processes which determine water quality;
- changes in flow volumes will alter residence times and dilution;
- increased atmospheric CO_2 will affect the rate at which this gas is dissolved in water, and hence the rate of operation of many processes;
- a change in soil properties and flow pathways will alter the transport of chemical load from river catchment; and v) changes in inputs of chemicals to the catchment – perhaps due to the effects of climate change on agriculture – will alter water chemistry.

Predictions of the direct effects of climate change on aquatic ecosystems are very complex, and projecting these in combination with other human impacts poses an even greater challenge. The consequences of human activities on freshwaters are considerable, ranging from:

- acidification by sulphur and nitrogen compounds;
- mobilisation of organic substances from soils;
- accelerated erosion and sedimentation in river channels;
- damming and diversion of river flows;
- eutrophication by nitrogen and phosphorus compounds;
- structural alteration of rivers for flood prevention in the interests of agriculture;
- fragmentation of habitats; to
- introduction of alien species and selective removal of others.

All of these impacts interact with climate change. Large EU projects such as Euro-limpacs (http://www.eurolimpacs.ucl.ac.uk/) address this challenge by focusing on the key drivers of aquatic ecosystem change (land-use, nutrients, acid deposition and toxic substances) and conducting in each case a rigorous examination of the currently available evidence for such interactions, carrying out experiments to assess potential responses of different aquatic systems to future climate change and developing models that simulate the key processes involved.

With respect to water quality, most climate change impacts can be attributed to changes in either discharge or in water temperature. To a minor degree climate change may also affect the levels of direct atmospheric input of nutrients and other elements to the surface waters. The discharge controls dilution and residence times. When temperature increases, oxygen diffusion to water decreases and biological activity is enhanced. The shortening of ice cover season may have positive impacts particularly in shallow lakes.

Higher water temperature and variations in runoff are likely to produce adverse changes in water quality affecting human health, ecosystems and water uses. More intense rainfall will lead to increase of suspended solids in lakes and reservoirs due to soil fluvial erosion and pollutants will be introduced. Higher surface water temperatures will promote algal blooms and increase the bacteria and fungi content. This may lead to a bad odour and taste in chlorinated drinking water and the occurrence of toxins. Moreover, even with enhanced phosphorus removal in wastewater treatment plants, algal growth may increase with warming over the long term. Higher runoff is expected to mobilise fertilisers and pesticides to water bodies in regions where their application time and low vegetation growth coincide with an increase in runoff. (Kundzewicz et al., 2007). Results from experiments with increased temperatures (3^{o}C above ambient) indicate that overall abundances of most macroinvertebrate taxa will not be severely affected by the predicted temperature rise (Feuchtmayr et al., 2007).

Diatoms are often used as bio-indicators in quantitative reconstruction techniques to obtain climate records that extend beyond instrumental measurements. Paleolimnological evidence for climate change over the last 200 years were compared with instrumental climate data for the same period at seven European remote mountain lakes (Battarbee et al., 2002).

The results indicated the need to use multi-proxy approaches. The ability to distinguish between climatic and anthropogenic influences in the past is needed to back up predictions of future water quality responses.

Moiseenko and Gashkina (2007) estimated migration coefficients of trace elements in different climatic zones from tundra to arid zone. Climate-related processes such as evapotranspiration and humification contributed to differences in enrichment although anthropogenic loading was the predominant reason for high coefficients of concentration of trace elements. Unexpectedly high nickel concentrations in high alpine lake waters were attributed to solute release from the ice of active rock glacier in the catchments as a response to climate warming (Thies et al., 2007). Changes in climate may also lead to increased long range transport of dust, followed by increased atmospheric deposition of soluble reactive phosphorus and changes in lake water quality. For instance, Pulido-Villena et al. (2007) found a significant decrease in phytoplankton species diversity after atmospheric inputs of soluble reactive phosphorus with seasonal pattern similar to Saharan dust outbreaks.

Climate change has also been proposed to explain recent, widespread increases in concentrations of Dissolved Organic Carbon (DOC) in surface waters. Montheith et al. (2007) found, however, that changes in the chemistry of atmospheric deposition provided the only regionally consistent explanation for the upward trends in surface water DOC concentrations in time series data from 522 remote lakes and streams in North America and northern Europe. Their findings suggest that threats of widespread destabilization of terrestrial carbon reserves by gradual rises in air temperature or CO_2 concentration may have been overstated (Monteith et al., 2007).

The development of water quality will depend essentially on the future evolution of human activities. The effectiveness of wastewater treatment, agricultural practices, water withdrawals and many other factors will play an important role. Successful implementation of the European Water Framework Directive and the Urban Wastewater Directive can greatly help to lower the harmful impacts of climate change.

1.2 Consequences for society

This section will give an overview of the challenges resulting from water-related climate impacts to European societies. Changes in the hydrological, biological and chemical characteristics of the European water resource will have consequences for economic activities, but also for human health and well-being. The following sections give an overview of the impacts of climate-driven changes in water resources on important economic sectors and on human health. In addition, a brief analysis is made of the role of climate change in the context of water use conflicts and cross-border management principles.

1.2.1 Impacts on important sectors

Agriculture

Agriculture is highly dependent on environmental conditions – inter-annual climate variability is one of the main sources for uncertainty in crop yields already today. Agriculture also belongs to the main water users in Europe, using ca. 38% of the total abstracted water. However, the demand for irrigation water differs strongly between regions – in southern Europe agriculture uses 50-80% of abstracted water, in northern Europe this share is below 5% (Eisenreich et al., 2005).

Increased water shortages as a result of a changing climate would therefore have a significant impact on the agricultural sector. In central Europe, the projected shifts in precipitation patterns would reduce water availability during the vegetation period in summer and possibly increase the demand for irrigation water. Rising temperatures and evaporation rates would exacerbate water scarcity problems especially in southern Europe, where the dependency on water for irrigation is considerably higher. The consequences for farmers could be higher costs for irrigation, production losses or the complete loss of land due to desertification (UBA forthcoming). In Spain, one fifth of the land is currently at risk of turning into deserts, as for instance in the Guadalquivir river basin, where years of over-abstraction to irrigate rice fields and olive groves have led to serious water deficits (Dworak et al. 2007b). In coastal areas, the water shortage and land-loss problem could be exacerbated by sea-level rise and subsequent salinisation processes.

Livestock production may also be affected by increases in temperatures and drought frequency. Heat stress may increase the mortality of animals, especially if kept in intensive livestock systems. Droughts may also reduce the productivity of grasslands such that they are no longer sufficient for livestock (Turnpenny et al., 2001; Holden and Brereton, 2002; Holden et al., 2003).

Higher precipitation in the northern latitudes of Europe, combined with an increase in temperature, may prolong vegetation periods, increase crop yields, allow the cultivation of new crop species or make new land available for farming. On the other hand, increased temperatures will also lead to higher evaporation rates, and net effects are likely to vary strongly depending on regional circumstances. For example, Downing et al. (2003) modelled increases in irrigation use in England of around 20% by the 2020s and around 30% by the 2050s due to climate change. However, higher temperatures and humidity might also lead to production losses due to a rise in certain plant diseases (e.g. fungi) or the introduction of new pest species. Overall, the largest risk associated with higher precipitation will probably lie in the anticipated increase in the frequency and intensity of extreme weather events. Subsequent flooding or the occurrence of hailstorms could seriously impact crop yields, and recurring flood events could even render agricultural land-use in flood-prone areas uneconomical (UBA, forthcoming).

Changes in temperatures and water resources will be accompanied by a change in atmospheric CO_2 content, which will have a fertilising effect on crop growth for certain species (Long et al., 2006). Overall, the combined impacts are expected to lead to small increases in European crop productivity. However, there will be significant variations, and regionally reductions in yield and severe socio-economic impacts are likely to occur (Olesen et al., 2007; Santos et al., 2002).

Industry and energy

After agriculture, industry is currently the second largest user of water on a global scale (Fry, 2005) and its water use is projected to further increase strongly (Millennium Ecosystem Assessment, 2005a, b). For Europe, data from 1997 indicate that industrial water use (excluding the energy sector) uses about 10% of total water abstraction (ETC/IW, 1997). The amount of water used varies widely from one type of industry to another. Most industrial products need water in several steps of the production process. Industries that use large amounts of water include the paper and pulp, textile, leather (tanning), oil and gas, chemical, pharmaceutical, food, energy, metal and mining sub-sectors.

In Europe, large industrial water consumers can be found in France, Germany, Italy, Spain, and Sweden (EEA, 1999) of which those in regions of water scarcity will be most affected by climate change. In such areas an intensified competition with other uses for water resources can occur (see Section 1.2.3).

The **production of energy and electricity**, as a particular sub-sector of industry, is strongly dependent on water, be it for cooling in power plants, hydropower or biomass production. The energy sector will thus be particularly affected by climate change.

- **Hydropower** may benefit from increased hydropower potential in Nordic countries, where Scandinavia and northern Russia could see an increase of 15-30% (Kirkinen et al., 2005). In contrast, southern and south-eastern European countries can expect reductions of 25% or more of hydropower potentials due to reduced river runoff (Veijalainen and Vehviläinen, 2006; Andréasson et al., 2006 and Lehner et al., 2005). In areas with increased precipitation and runoff, dam safety may become a problem due to more frequent and intensive flooding events.
- The generation of electric power in **thermal power stations** (in particular coal-fired and nuclear) often relies on large volumes of water for cooling. It has become apparent during recent heat waves and drought periods that electricity generation in thermal power plants may be affected by increases in water temperature and water scarcity. In the case of higher water temperatures the discharge of warm cooling water into the river may be restricted if limit values for temperature are exceeded. This may force plant operators to work at reduced capacity or even temporarily close plants, with potentially serious consequences for supply. Electricity production has already had to be reduced in various locations in Europe during very warm summers (e.g. 2003, 2005 and 2006). In the second case, in regions where water will become increasingly scarce, the use of water for cooling may conflict with other water uses (UBA, forthcoming).
- **Biomass production** may be affected in different ways. On the one hand, increased precipitation, higher temperatures and higher atmospheric CO_2-concentrations might be beneficial for biomass production. On the other hand, similar to other agricultural production, biomass cultivation may suffer both from water scarcity and drought or from flood damage to harvests, from more frequent extreme weather conditions or from a higher incidence of pests and fungi.
- Intense precipitation events, increased flood risk, and sea level rise may increase the risk of **infrastructure damage** (generation and supply). In some Member States (e.g. UK and Finland) nuclear power plants, nuclear fuel reprocessing or nuclear waste sites are located near the coast, which could lead to security problems as a consequence of sea level rise. Furthermore, energy supply infrastructure, in particular transmission grids, might be endangered and damaged by flooding events and avalanches. In addition, transmission networks may be affected by climate change impacts that are not related to water resources, such as extreme cold and the melting of permafrost soils (UBA, forthcoming). Also, since cable resistance increases with temperature, a warming climate may also lead to power losses in transmission in southern countries (Aguiar et al., 2002).

- Changes in temperature will also affect **seasonal electricity demand patterns**. On average, the demand for heating in winter is likely to decrease, while the demand for cooling during the summer months will increase. Generally, it may become more challenging to meet energy demands during peak times due to more frequent heat waves and drought conditions (Rothstein et al., 2006).

Transport

Climate change may affect the transport sector mainly through infrastructure damage, and through effects on the navigability of waterways. The likely increase in extreme weather events, but also the increase in temperatures, may cause damage to transport infrastructure or affect road and rail safety. In particular, flooding of underground rail systems and roads with inadequate drainage may be a problem (Alcamo et al., 2007).

Climate change may affect Inland Waterway Transport (IWT) by changing water levels in rivers, reservoirs, and lakes, and by increasing the frequency of floods and droughts (EEA, 2007). Constraints are especially to be expected in extreme cases, for instance extended drought periods and low water flows. Low water levels may reduce loading capacity and affect transport prices. To a lesser extent, IWT may suffer from the projected increase in frequency of floods and storm surges, which could temporarily disrupt transport. In addition, changed patterns of sediment transport may be a problem leading to increased cost for maintenance.

In some instances, IWT might also benefit from climate change. In winter, higher temperatures and reduced ice cover on rivers could improve conditions for IWT, and some regions may benefit from increased precipitation (UBA, forthcoming).

1.2.2 Human health

Climate change impacts may significantly affect human health by a variety of stressors. Increased temperatures are predicted to cause more (predominantly cardiorespiratory) deaths and illness, cold related deaths on the other hand are likely to decline with milder winters (Confalonieri et al. 2007). Health impacts related to water arise mainly from more frequent storms and floods. In combination with higher temperatures water may also provide the routes for spreading of new diseases:

- **Flash floods, coastal flooding**, and wind storms will increase the risk of immediate mortality and injury (Kirch et al., 2005). For example, the 2002 floods, which consisted of 15 major floods affecting Austria, the Czech Republic, Germany, Slovakia, and Hungary, caused around 250 deaths around Europe (EEA, 2004).

- Decreases in water availability during drought periods can increase **water borne diseases**, and climate-induced changes in the geographic distribution and biological behaviour of vector organisms of vector-borne infectious diseases (e.g., malaria-transmitting mosquitoes) and infective parasites might increase the potential transmission of such diseases. However, the re-emergence of endemic malaria in Europe due to climate change is very unlikely, though an increased risk of localised outbreaks is possible, if suitable vectors are present in sufficient numbers[3].
- In developed countries, flood-related water-borne diseases are usually contained by well-maintained water and sanitation services (Confalonieri et al., 2007).
- Climate change is also likely to affect **water quality** in Europe (see section 1.1), and hence the risk of contamination of public and private water supplies. Negative impacts include higher runoff of pollutants, decreased dilution, algal blooms and increase of bacteria and fungi content due to higher temperatures, and saline intrusion in coastal aquifers (Footit et al., 2007).

1.2.3 Potential political conflicts over water

Potential political conflict over water under a scenario of climate change is most likely to arise from water shortages. Other conceivable causes could be conflicting political programmes or an increase in flood events in transboundary river systems.

- Under a warming climate the water demand of different uses might cause political conflict over water allocation. The demand for water by different sectors such as agriculture, tourism, electricity and households is likely to increase precisely during the times when there is likely to be the greatest water stress. For example, if water is scarce water use for irrigation might conflict with minimum flow regimes needed for cooling water (UBA forthcoming). Adaptation efforts thus require an integrated approach that takes both water needs and adaptation options of all sectors into account, and ensures that all water users contribute to more efficient water use and savings. Adaptation may also require the prioritisation of water uses. Where rivers cross national borders, the riparian states need to find a consensus on the allocation of water resources (see also Section 1.2.4).
- Similarly, conflicts may arise between environmental objectives of different political approaches. For instance, the aim to increase the share of renewable energies is likely to lead to a more widespread cultivation of energy crops. Since they tend to be rather water-intensive, it is necessary to adjust this development to the need to reduce water use in agriculture (Dworak et al., 2007a, 2007c).

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[3] A case of *Plasmodium vivax* malaria was diagnosed in Corsica in August 2006. This is the first case of autochthonous transmission of malaria to be reported in the region since 1972. Malaria is a notifiable disease in mainland France (including the Mediterranean island of Corsica). Rare cases of malaria have been observed after bites from infected mosquitoes that had been imported from endemic areas into airports and sea ports or by transmission via contaminated blood transfusion or tissue grafts. Corsica was endemic for malaria before 1953 and from 1965 to 1971.

- Flood events are predicted to become more severe and frequent throughout Europe. Factors exacerbating natural floods are anthropogenic alterations to the catchment (surface sealing, land use changes) and to the water course (straightening). The impact of a flood in a downstream part of the river can be intensified by activities or flood protection measures in the upstream catchment. This necessarily calls for consolidated action at a river basin wide scale, which is especially difficult when two or more states are involved. Most transboundary rivers in Europe have founded a transnational body to co-ordinate action in the river basin[4]. Under a climate change scenario, these structures might be put to the test if more frequent and severe flood events collide with plans for economic development.

1.2.4 Cross-border water management principles

Cross-border water management will play an important role in adapting to increased flood and drought events. Many rivers in Europe face quality and flooding problems, or water scarcity and allocation problems, and both can be exacerbated by climate change impacts. Thus, integrated management of water resources across national and administrative borders will become even more important under a changing climate.

Several countries sharing a transboundary river basin already have according management plans in place, and cross-boundary co-ordination in international river basins is strengthened by European legislation (Water Framework Directive). The four principle stages in transboundary water management embrace (drawing on Barraque and Mostert, 2006):

- **Convening**, i.e. bringing all stakeholders together.
- **Negotiating**, where the relevant “facts” have to be established, including the natural river discharge, present use and projected demand, and risk for flood events and causes. Then several options need to be developed and assessed.
- **Conclusion of an agreement,** which in the past has taken up to 100 years (in the case of the Alpine Rhine), but usually is in the order of several years depending on the conflict potential of the interests.
- **Implementation of the agreement** which might prove difficult if the lower level government responsible for implementation and water users have not adequately been involved in the negotiation process.

This mechanism is operating successfully in Europe, building on the established co-operation structures and common water management policies throughout Europe.

One prominent example is the co-operation between Portugal and Spain who share four principal rivers: the Miño/Minho, the Duero/Douro, the Tajo/Tejo, and the Guadiana. All four start from Spain and then enter Portugal, except for the Minho/Miño, which is a boundary between both countries (Barraque and Mostert, 2006). Spain started plans in the 1920s to ‘regenerate’ the country through the construction of dams and aqueducts or canals devoted to store and transfer water, both to generate electricity and to irrigate land for agriculture.

[4] For example, after the floods in late 1993 at the Rhine, it was decided that the International Commission for the Protection of the Rhine (ICPR) should become active in flood protection and finally published an Action Plan on Flood Protection in 1998 (ICPR, 1998).

Portugal feared that this would eventually reduce the volumes of water available for Portugal depending on Spanish born rivers for 40% of the total flows. Several conventions on the use and allocation on water resources were signed incorporating increasingly the idea of sustainable water management.

1.3 Adaptation and policy approaches

According to the definition used by the IPCC, adaptation is any 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, 2001). Adaptation should thus reduce the sensitivity to potentially damaging impacts, but also enhance the capability to capture any benefits of climate change.

While adaptation will to a large extent occur at decentralised levels, adaptation measures being implemented locally and regionally, a strong role for governments and for policy-driven adaptation is nevertheless recognised widely. Government action can contribute to motivate early adaptation and to support efforts by private actors. A need for policy action is identified for instance with regard to the following fields (Berkhout, 2005; Stern, 2006; UK Environment Agency and DEFRA, 2006):

- Research, information and communication.
- Regulation and standards.
- Public infrastructure.
- Early warning and disaster relief.
- Regulating the distributional impacts of adaptation.
- Embedding adaptation in sectoral policies.

The following sections give a brief overview of key water-related adaptation measures (Section 1.3.1), and discuss policy implications and approaches at European level and internationally (Section 1.3.2 and 1.3.3).

1.3.1 Adaptation measures

This section examines measures to adapt to climate-driven changes in water regimes in Europe, with a focus on three complementary (but contrasting) approaches (infrastructure development, landscape management, demand management). Table 2 gives an overview of potential adaptation measures.

Table 2: Adaptation measures in water management

Flood protection
Technical flood protection (e.g. raising dikes, enlarging reservoirs, upgrading drainage systems etc.)
Allowance for higher flows/higher flood risk in flood defence structures
Natural retention of flood water (e.g. floodplain restoration, change of land use)
Restriction of settlement/building development in risk areas
Standards for building development (e.g. permeable surfaces, greening roofs, use of outdoor space to detain floodwaters etc.)
Improving forecasting and information
Improving insurance schemes against flood damage

Drought/low flow protection
Technical measures to increase supply (e.g. new reservoirs increasing reservoir volumes, water transfers, desalinisation etc.)
Increasing efficiency of water use (e.g. leakage reduction, water re-use, more efficient irrigation, more efficient water use appliances, etc.)
Economic incentives (e.g. water pricing)
Restriction of water uses
Landscape planning measures to improve water balance (e.g. change of land use, reforestation, reduced sealing of areas)
Improving forecasting, monitoring, information
Improving insurance schemes against drought damage
Coastal zones
Reinforcing or heightening coastal protection infrastructure
Retreat strategies, e.g. managed realignment of dams
General adaptation measures
Awareness raising, information campaigns
Building of financial resources

Source: Benzie et al. 2006.

Infrastructure development

Technology and infrastructure play an important role in the management of water resources, both with regard to ensuring water supply and wastewater management, and with regard to protection against floods. Consequently, adjustments of existing infrastructures or investment in new technologies can be used for adaptation.

Technical adaptation measures include flood protection measures (e.g. upgrading of flood defence structures in response to more frequent or intense flooding events), but also measures to increase supply, such as the creation of new water storage reservoirs, desalination plants, the construction of water transfers from one river stretch or water body to another, or the modification or extension of infrastructure to collect and distribute water to consumers and to dispose of wastewater (UBA, forthcoming; EEA, 2007).

Investments in physical water infrastructure may improve the flexibility of water management and increase its capacity to buffer the effects of hydrological variability. However, they may run the risk of conflicting with environmental protection concerns, for instance the water quality objectives of the Water Framework Directive.

Furthermore, infrastructure investments are often associated with high costs, which have to be weighed against the potential benefits to be gained. The cost-effectiveness of technical adaptation measures tends to depend on the exactness of predictions of climate change impacts. However, while it is often possible to identify trends (e.g. increase in precipitation and thus likely increase in flooding), the exact magnitude of changes at a regional or local scale is usually not known, since projections of climate change impacts on water resources are subject to large uncertainties.

Thus, the current knowledge about climate change impacts calls for flexible solutions, robust strategies and win-win solutions that will be functional under different possible scenarios. High-cost, irreversible investments should therefore be treated with care in the context of climate change adaptation.[5]

Landscape management approaches

Land use and landscape management are strongly linked to the management of water resources. The way land is used influences the ability of the soil to hold back precipitation or flood water. The sealing of large areas, for instance in urban centres, increases the risk of flash floods, while sustainable managed soils in agriculture or forestry may be able to store large quantities of water and thus act as a buffer during intense precipitation events.

Land-use measures that may support adaptation to climate change include for instance forestation, conservation agriculture and extensification of agricultural land use, flood plain restoration, the conversion or restoration of natural land cover, or wetlands restoration. Such measures can help to improve flood prevention, control and mitigation, to regulate runoff and water supply, improve the quality of surface waters and groundwater; withhold sediments and reduce erosion. They can also stabilise river banks and shorelines and lower the potential of landslides, improve water infiltration and support water storage in the soil, and facilitate groundwater recharge (UBA, forthcoming).

Therefore, changes in land management may be an alternative to raising dykes and dams and to large investments in physical flood control structures. In the Netherlands, for instance, spatial planning projects are being implemented that limit development along river ways in order to reduce vulnerability to climate change-induced increases in flood risk. The “Room for the River” Programme recognises the need to widen the river floodplain, rather than increasing the height of the dykes.[6]

The protection of ecosystems, e.g. wetlands, should play an important role in managing the water balance of landscapes. Payment schemes (**Payments for Ecosystem Services** - PES) can be used in order to adequately value these ecosystem services and to encourage the protection of such ecosystems and their capacity to provide water-related services (UNECE, 2006).

Adapting spatial planning to climate change impacts can also mean to **remove assets from high risk areas**. In some cases, holding back flood waters through technical measures may not be possible or may be too costly in the long term. In flood-prone areas along rivers where damage to infrastructure, buildings and property cannot be prevented at reasonable cost, it may be necessary or desirable to restrict building development, or even to consider resettlement to areas that are less at risk. Similarly, managed retreat along coastlines can be an alternative to building new dykes.

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[5] Key messages of the CIS workshop on River Basin Management Plans and Climate Change, 21 November 2007.
http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/implementation_conventio/workshop_november&vm=detailed&sb=Title

[6] http://www.ruimtevoorderivier.nl/.

While such measures may not easily be accepted by those concerned, they may still be considered in certain cases since they proactively avoid damage, rather than providing assistance and support after a natural disaster has occurred. Restriction of settlement or resettlement does not necessarily have to be imposed by government through coercive instruments such as regulation or zoning, but may be encouraged through “soft” tools such as market based instruments or tax incentives (Akong et al., 2006).

In this context, **information about risk** and increasing awareness is important to support adaptation. For instance, the mapping of risks (as required by the Floods Directive, see Section 1.3.2) and adequate information about these risk maps is essential for stakeholders to make informed decisions and to take potential future climate change into account.

Agriculture as a key form of land use will play a crucial role in adaptive spatial planning approaches. Reducing the area under irrigation, or growing less water-intensive crops in water scarce areas could be an important contribution to adaptation. Intensive agriculture in flood-prone areas is at risk of substantial economic loss in the case of flooding. On the other hand, the increased challenges for flood risk management will create a demand for new ways of accommodating flood water and managing flows, which may increase economic opportunities for water farming (UK Environment Agency and DEFRA, 2006). For instance, crop farming in flood risk areas may be replaced by extensive grassland management. Such changes in land use could be a win-win solution, since they may reduce risk of harvest loss and simultaneously help to conserve water and hold back flood waters.

Improving the efficiency of water use and reducing demand

In many regions of Europe, climate change impacts will result in greater water scarcity, i.e. a reduced supply of water relative to demand. Climate change can directly decrease the availability of water resources (see Section 1.1), and it can boost the demand for water from users. Both may occur at the same time - for instance, in a hotter and drier climate, the demand for irrigation water is likely to increase while the available quantity of water is shrinking.

Adaptation to increased water scarcity may include technical changes that improve water-use efficiency, demand management, and institutional changes such as an improvement of the tradability of water rights (Kundzewicz et al., 2007).

Demand management uses economic incentives to encourage changes in consumer behaviour that lead to a more sustainable and efficient use of water and help to reduce overall water consumption. Adequate **water pricing** in particular is seen as a means to provide incentives to use water resources more efficiently, and to ensure that all sectors contribute to the recovery of water service costs. Water pricing is most effective when based on **metering** of water consumption (volume-based pricing). However, the affordability of water services also for the least wealthy households needs to be ensured (European Commission, 2007c; see also Section 1.3.2).

Adaptation to water scarcity can make use of existing **technical approaches** to improve the efficiency of water use. Measures such as rainwater collection and water re-use and recycling can deliver important contributions to reducing the use of fresh water.

Demand management approaches can also include **public information** measures, in order to create a higher awareness about the effects of climate change and the need to use water resources more responsibly and efficiently.

Regulation can also be helpful or necessary in the context of climate change and water scarcity. For instance, in the case of droughts or severe water scarcity situations restrictions of water use and water allocation or rationing schemes may have to be imposed. Authorities may also issue mandatory water use standards for appliances or for new buildings to encourage efficient water use.

Information and risk management

Information of the public and awareness-raising among stakeholders as well as improved risk management tools are crucial to reduce vulnerability to climate-related changes in water resources and to support adaptation. Information measures such as risk mapping can create a higher awareness and acceptance among the public and stakeholders on the effects of climate change and the need to adapt. In addition, forecasting and early warning systems for both floods and droughts are essential to avoid damage from extreme events (Eisenreich et al., 2005).

Insurers may be a natural partner for policy-makers in identifying and quantifying risk, communicating risk, and developing innovative risk management proposals (CEA, 2006). Insurance schemes and financial instruments may be adapted to provide for a more equitable sharing of risk.

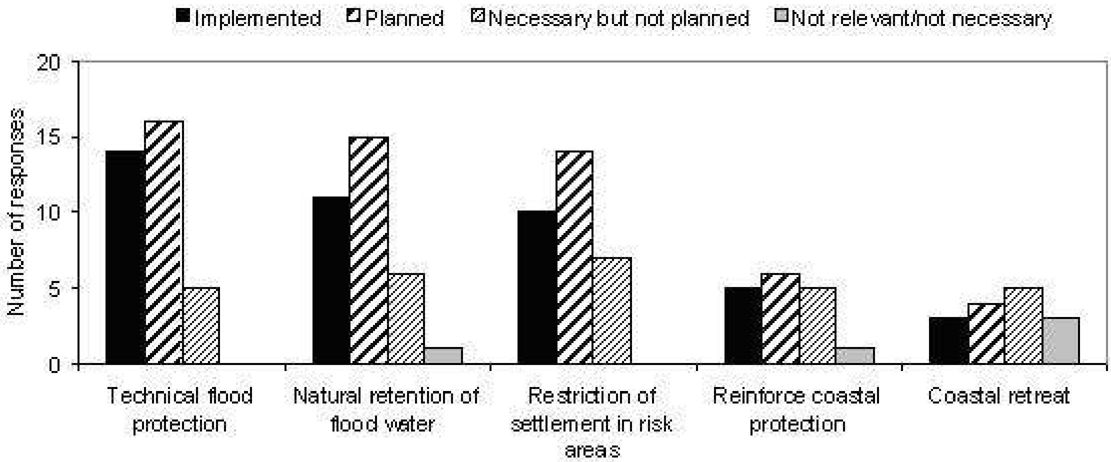
Awareness and current status of implementation of adaptation measures in Europe

A European survey revealed that water managers are highly familiar with scientific evidence on climate change impacts, and are aware of the resulting challenges for their countries (Benzie et al. 2006, EEA 2007). Climate change impacts and adaptation issues are rising on the national agendas, and many countries have undertaken studies on climate change impacts and vulnerability in key sectors (see for instance EEA, 2005a). However, the implementation of adaptation activities seems to be lagging behind, at least in certain areas, and few governments seem to move on to implementing adaptation initiatives and incorporating long-term climate change risks into actual investment or development plans on a national and local scale (EEA, 2005a; Gagnon-Lebrun and Agrawala, 2006; Stern 2006).

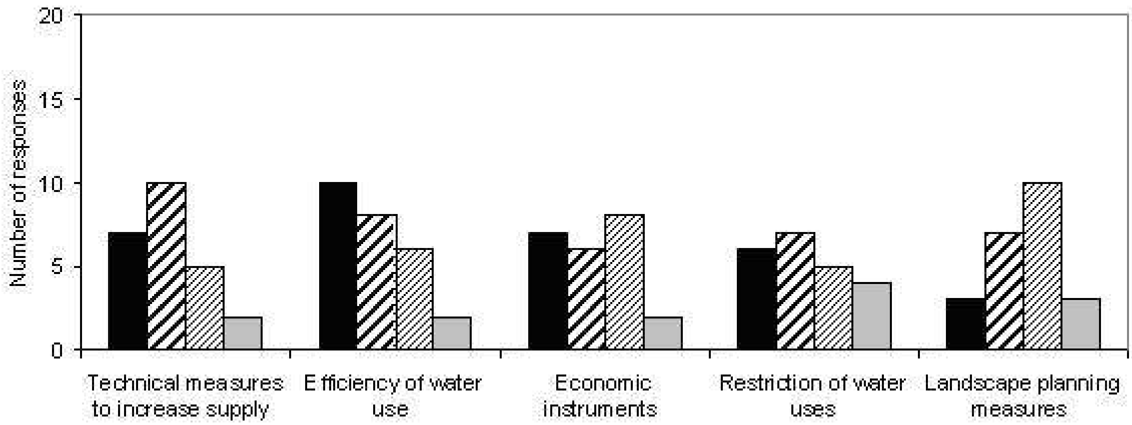
An evaluation of adaptation measures and initiatives undertaken by Member States in response to water-related climate change impacts has shown that adaptation activities currently seem to be focused on flood management and defence, while adaptation measures related to the management of water scarcity and drought, although recognised as equally damaging, do not yet seem to be widespread. Among the measures that are considered useful, but where implementation is not yet far advanced, are “economic instruments (e.g. water pricing)”, “landscape planning measures to improve water balance”, and improvement of insurance schemes both against flood and against drought damage (Benzie et al., 2006).

Figure 2 shows the survey results for adaptation measures related to flood risk management (a), water scarcity and drought (b) and general measures related to information, monitoring and insurance (c). For a list of individual adaptation measures, the graphs show how many respondents indicated that these measures have already been *implemented*, are *planned*, are considered *useful but have not yet been planned or implemented*, or are considered *not relevant or not necessary*.

a) Measures related to flood risk management



b) Measures related to management of water scarcity and drought



c) Measures related to information, monitoring, insurance

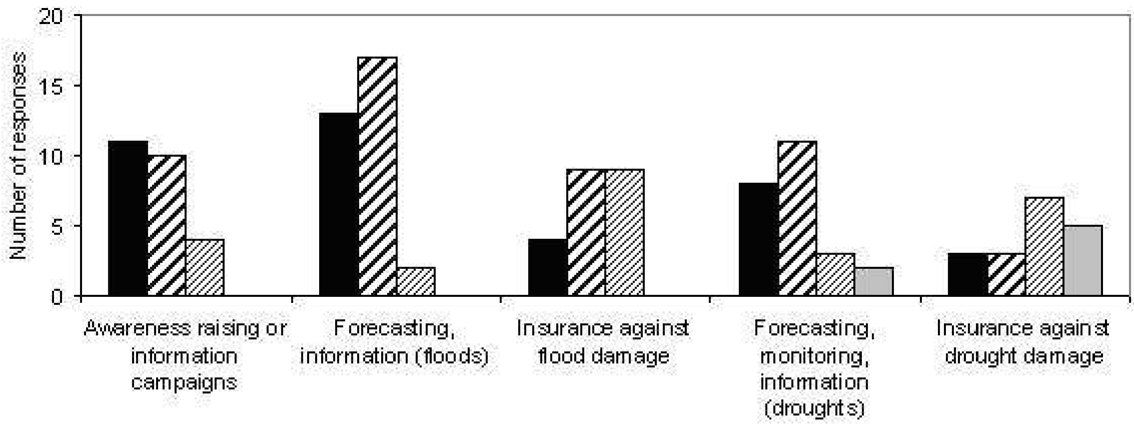


Figure 2: Implementation of adaptation measures in Europe – survey results among European water managers. Source: Benzie et al. 2006.

1.3.2 *Policy approaches at European level*

Adaptation to water-related climate change impacts is gaining relevance both on the political and the research agenda in Europe. Recent reports by the European Environment Agency (EEA, 2005b, 2007) as well as a number of EU level conferences and events [7] address the issue.

The Green Paper on Adaptation

The framework for policy action on adaptation at EU level is set by the **Green Paper** launched in June 2007 (European Commission, 2007a). The drafting of the Green Paper was supported by work on adaptation undertaken by the European Climate Change Programme (ECCP). It represents the first comprehensive review of the discussion on adaptation in Europe, and sets the scene for adaptation efforts in the EU. The Green Paper examines climate change impacts in Europe and the case for action and policy responses in the EU.

It recognises the specific problem structure of adaptation: adaptation cannot be delivered by one single policy, but requires concerted action in different policy areas. Consequently, the Paper analyses the scope for integrating adaptation efforts into different policy areas.

The Green Paper makes the case for early action, stressing that early adaptation will bring economic benefits and may even help to gain competitive advantages through the development of new technologies. EU level action is justified based on the fact that climate change impacts will not stop at national borders or follow administrative boundaries, and that effective adaptation will in many cases require a co-ordinated and cross-boundary approach. In addition, the Green Paper points to the fact that for many of the sectors relevant for adaptation, for instance water and agriculture, integrated Community policies are already in place, which can be harnessed for supporting adaptation. Finally, the exchange of information on national approaches to adaptation is mentioned as an objective of EU level action.

The Green Paper analyses how adaptation efforts could be integrated into existing sectoral EU policies, [8] how Community funding programmes could take climate change and adaptation into account, and also explores the scope for developing new policy responses, in particular with respect to financial services and insurance, and spatial planning. The Green Paper announces that a systematic check of how climate change will affect all Community policy and legislation should be carried out by 2009.

With respect to water policy, the Green paper emphasises the importance of applying economic instruments and the user pays principle across all sectors, and to create incentives to reduce water consumption and the efficiency of water use. It states that for flood protection, soft non-structural measures based on sustainable land-use and spatial planning should be given priority, although structural flood defences will continue to play an important role.

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[7] See for instance http://ec.europa.eu/research/environment/newsanddoc/other_pubs_en.htm and http://www.climate-water-adaptation-berlin2007.org/.

[8] Agriculture and rural development, industry and services, energy, transport, health, water, marine and fisheries, ecosystems and biodiversity, other natural resources.

In addition to early action in the EU (pillar I), the Green Paper addresses: the integration of adaptation into EU external action (pillar II), the need to reduce uncertainty through integrated climate research (pillar III), and the involvement of European society, business and public sector in the preparation of coordinated and comprehensive adaptation strategies (pillar IV).

The Green Paper was subject to a public consultation that ended in November 2007. A Communication on adaptation is expected for end of 2008.

EU water policy

Developments in EU water policy have only recently begun to take climate change impacts into account. The **Water Framework Directive** (WFD) does not explicitly make reference to climate change. However, it addresses several issues that are relevant in a climate change context. For instance, the mitigation of floods and droughts, which are likely to become more frequent in a changing climate, is one of the main purposes of the Directive (Art. 1e WFD). Also, the WFD provides a flexible framework for water management (cyclical review of plans and measures), and tools that can help to promote water use efficiency and improve the conditions for adaptation.

Climate change impacts may exert pressures on water bodies and thus interfere with several of the key phases and with the delivery of key environmental objectives of the WFD (Eisenreich et al., 2005; Wilby et al., 2006). In the context of the WFD Common Implementation Process (CIS), an activity was launched in 2006 to explore potential adaptation strategies in the context of the European water policy. A workshop in November 2007 specifically addressed the linkages between climate change impacts and WFD implementation. Issues raised during the workshop included the possibility of type changes of water bodies due to climate change, the potential need to adjust reference conditions, and the need to ensure that monitoring tools can detect climate change impacts on water bodies.

Climate change may be addressed already in the first WFD River Basin Management Plans (RBMP) due in 2009. Recommendations from the CIS workshop suggest that a chapter should be integrated into the first RBMPs that summarises existing knowledge about impacts and outlines future steps for addressing these impacts. A "climate check" of the Programme of Measures should be carried out in order to ensure that measures planned today will still be viable and cost-effective under changing climate conditions, and priority should be given to win-win solutions and no-regret measures.[9]

In 2003, a water scarcity initiative was established under the WFD common implementation process. In July 2007 the Commission published a **Communication on water scarcity and droughts** (European Commission, 2007c). The communication recognises water scarcity and drought as a major challenge that affects a large share of the European population and territory, and that will be exacerbated by climate change impacts.

[9] See key messages from the Workshop of the CIS-Working Group, 20-21 November 2007, at http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/implementation_conventio/workshop_november&vm=detailed&sb=Title

It presents policy options to address this challenge, placing the need to use water more efficiently and to develop more sophisticated demand management strategies at the centre of its deliberations. It outlines the way forward both at national and EU level for a number of challenges:

- Putting the right price tag on water – better water pricing policies.
- Allocating water and water-related funding more efficiently.
- Improving drought risk management.
- Considering additional water supply infrastructure.
- Fostering water efficient technologies and practices.
- Fostering the emergence of a water-saving culture in Europe.
- Improve knowledge and data collection.

Currently, no new legislation on water scarcity is envisaged. Instead the effective and comprehensive implementation of the WFD is seen as the best way forward to address water scarcity and drought. Since adaptation to climate change will in many cases be equivalent to coping with intensified water scarcity, the policy options outlined in the Communication can be considered as important tools for climate change adaptation. The Commission plans to present a report on progress towards the set goals in 2008.

In December 2007, agreement was reached between the European Parliament and the Council on a **Marine Strategy Directive**. The Directive[10] follows in many aspects a similar approach as the WFD. Member States will have to identify pressures and respond to them by defining specific measures. The Marine Strategy Directive identifies climate change as one of the main pressures on marine waters, alongside the impacts of commercial fishing, loss or degradation of biodiversity, and contamination. The protection of the marine environment should be flexible enough to allow for an adaptation to changing pressures and impacts which may for instance be caused by climate change. While it does not suggest any specific adaptation measures, the Marine Strategy provides a framework and policy instruments that can be used to promote adaptation.

The Marine Strategy Directive represents the environment pillar of the European Maritime Policy. A policy package on integrated maritime policy launched by the Commission in October 2007 announces work on a strategy for mitigation of climate change and adapting to climate change effects in coastal regions, and pilot actions to reduce the impact of and adapt to climate change in coastal zones (European Commission, 2007e, 2007f). The 2006 Green Paper on Maritime Policy, which provided the basis for the development of the integrated Maritime Policy package, mentions that adaptation strategies including the organisation of sea defence may be required to manage risks for coastal and offshore infrastructure resulting from sea level rise, increased flooding and storm surges. It also mentions that Mediterranean coastal zones are likely to be affected by changing precipitation patterns, and that an increased need for desalinisation may result from this (European Commission, 2006).

[10] Commission's proposal text. Consolidated version not yet available as of 19 December 2007.

The new **EU Directive on flood risk management**,[11] which entered into force in November 2006, introduces new instruments to manage risks from flooding, and is thus highly relevant in the context of adaptation to climate change impacts.

The Directive introduces a three-step approach. First, Member States have to undertake a preliminary assessment of flood risk in river basins and coastal zones. Where significant risk is identified, flood hazard maps and flood risk maps have to be developed. Finally, flood risk management plans must be developed for these zones. These plans have to include measures that will reduce the potential adverse consequences of flooding for human health, the environment cultural heritage and economic activity, and they should focus on prevention, protection and preparedness.

The rationale of the proposal recognises that climate change, together with inappropriate land use management and increasing human settlements and economic assets in floodplains, might increase the scale and frequency of floods in the future. The Directive text itself stipulates that projected climate change should be taken into account in the assessment of future flood risk (Art. 4).

Agricultural Policy

The **Common Agricultural Policy** (CAP) may influence the vulnerability of European agriculture to climate change impacts through both of its pillars (direct payments and rural development funding). Payments under the first pillar used to be coupled to the quantity of agricultural production and thus in many cases provided incentives for unsustainable and non-adaptive farming practices, such as the growing of irrigation-intensive crops in dry regions. Recent CAP reforms have reduced these incentives by de-coupling payments from production.

The Rural Development policy, the second pillar of the CAP, also provides opportunities to support adaptation. Both mitigation of climate change and adaptation to climate change impacts are acknowledged as priorities in Rural Development (RD) funding,[12] and Member States are encouraged to implement appropriate actions. RD programmes may for instance provide support to farmers for purchasing new equipment needed for adaptation, for the development of new products, processes and technologies, or for educational measures. The Green Paper on adaptation recognises that adjustments in the funding structure of the CAP may be necessary, and suggests that the CAP "Health Check" of 2008 could be an opportunity to explore options for such adjustments.

EU funding and adaptation

With their focus on environment, risk prevention and infrastructure, the funding instruments of the EU **cohesion policy** could play an important role for adaptation.

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[11] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. OJ L 288, pp. 27-34, 6.11.2007.

[12] Council Decision of 20 February 2006 on Community strategic guidelines for rural development (programming period 2007 to 2013) (2006/144/EC), published in OJ L 55 of 25.2.2006.

Currently no explicit funding of adaptation measures is foreseen under the EU cohesion policy. However, the different structural funding mechanisms are potentially important instruments for supporting adaptation. One of the main aims of the funds is tackle regional disparities and support regional development through actions including the development of infrastructure. Such regional disparities clearly exist also with regard to climate change impacts and adaptive capacity. Climate change impacts and adaptation measures will be beneficial for some regions and individuals and disadvantageous for others. One of the challenges of adaptation policy is to identify, protect and compensate those who will suffer damaging impacts, and to support those regions where particularly severe impacts are to be expected (UBA, forthcoming).

On the other hand, funding policies could be used to encourage adaptation by making financial support conditional upon taking into account climate change in projects supported through such investments, and upon ensuring that projects do not run counter to adaptation concerns (UK Environment Agency and Defra, 2006). The European Commission plans to "examine how climate proofing can be reflected and made operational in the programmes and projects adopted under the Cohesion Fund, Regional Development Fund, pre-accession instruments, Trans-European Networks Programmes, and infrastructure measures under the Rural Development Fund" (Green Paper on Adaptation).

The review of the EU's financial framework planned for 2008 and 2009 could be an opportunity to incorporate adaptation more explicitly into the structural funding programmes of the European Union (European Commission, 2007d).

Adaptation to water-related climate change effects will require further **research** on climate change impacts, in particular at regional level and with regard to extreme events, and on adaptation measures, their costs and effectiveness. The Framework Program for Research as the European Union's main instrument for funding research and development addresses climate change impacts. The first calls under the 7th Framework Programme FP7 include a number of projects related to climate impacts and adaptation research.

1.3.3 International level activities, adaptation and development

Climate change impacts on water are a concern globally, and impacts are most acutely felt in developing countries (IPCC 2007). Correspondingly, adaptation is an important issue in international policy activities, for instance under the United Nations Framework Convention on Climate Change (UNFCCC), and in bilateral and multilateral development co-operation activities.

In 2005, a five-year programme on adaptation was initiated under the **UNFCCC**,[13] which aims to improve the understanding and assessment of impacts, vulnerability and adaptation, and to make informed decisions on practical adaptation actions and measures to respond to climate change. Least developed countries draw up National Action Plans for Adaptation (NAPAs),[14] in which they define priorities for adaptation, with a focus on strengthening adaptive capacity and adaptation approaches on the local level.

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[13] Decision 2/CP.11: Five-year programme of work of the Subsidiary Body for Scientific and Technological Advice on impacts, vulnerability and adaptation to climate change. FCCC/CP/2005/Add.1., available at www.unfccc.int.

[14] http://unfccc.int/national_reports/napa/items/2719.php.

The UNFCCC also provides a database on local coping strategies which aims to facilitate the transfer of knowledge and experience on adaptation to specific hazards or climatic conditions.[15]

Under the UNFCCC, industrialised countries are obliged to support developing countries in adapting to climate change impacts. The Global Environment Facility (GEF) and three funds finance adaptation activities in developing countries: the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF) under the UNFCCC, and the Adaptation Fund under the Kyoto Protocol. The latter was operationalised at the Third Meeting of Parties to the Kyoto Protocol in Bali in December 2007 (IISD, 2007).

Development co-operation activities increasingly take climate change impacts and adaptation into account. Both the OECD and the EU have issued declarations recognising the necessity to support adaptation and to integrate climate change considerations in development co-operation (OECD, 2006; European Commission, 2003). The World Bank has begun to develop a "screening tool" to help assess the climate risk of development projects (World Bank and GEF 2006), and many donor governments and agencies are beginning to consider adaptation in their work (e.g. GTZ, 2007).

A number of **international research programmes** address climate change impacts on water resources and potential response strategies, such as the Co-operative programme on water and climate,[16] the International Human Dimensions Programme on Global Environmental Change,[17] the Unesco International Hydrological Programme (IHP),[18] and the International Geosphere-Biosphere Programme (IGBP).[19]

15 http://maindb.unfccc.int/public/adaptation/.

16 www.waterandclimate.org.

17 http://www.ihdp.uni-bonn.de/.

18 www.unesco.org/water/ihp/.

19 http://www.igbp.net/.

2 IMPACTS OF CHANGES IN WATER REGIMES ON LAND AND SOIL, AND THEIR ROLE IN CLIMATE CHANGE ADAPTATION AND MITIGATION

Climate change and related water stress are having, and will in future continue to have, impacts on land and soil around the world, including in Europe. The rural environment, meaning natural habitats, agricultural land and forests is under a variety of pressure, much of it anthropogenic, which is magnified by climate change stress.

This chapter looks at land and soil in terms of the natural and managed ecosystems found there (with forestry the subject of chapter three), and the impacts of climate change-related water stress on them. It also examines the role of land management, and options for both mitigation and adaptation, particularly in relation to agricultural land, which is the biggest land user in Europe, and with which much of Europe's biodiversity is intimately associated (Beaufoy et al., 1994; Bignal and McCracken, 1996; EEA, 2005; Reidsma et al., 2006). We conclude with a discussion on the extent to which land use policy should intervene in the climate challenge and consider the implications for a reformed Common Agricultural Policy (CAP) post-2013.

2.1 Expected impacts of climate change-related water stress on natural ecosystems

Climate change and associated changes in water regimes are predicted to be particularly damaging to natural ecosystems. The reason is two-fold. First, they are already under tremendous pressure from human land use requirements, pollution, and resource exploitation and are thus degraded and vulnerable to begin with. Given anticipated population growth and the impact of growing wealth, these pressures, unless effectively managed, will if anything increase in future.

Second, whilst an annual crop might be shifted elsewhere or to a more suitable species, it is harder to envision moving a wetland or a peat bog, both of which provide essential ecosystem services. These ecosystems may be resilient and cope with change up to a point, but when lost are not easily replaced.

The notion of "ecosystem services" has gained currency since the 1990s as a way of understanding how natural ecosystems are active participants in human well-being, which has not always been taken into consideration historically, except as sources of economically valuable goods like fish and timber, or as land to be converted to crops and pasture. Just as the value of natural ecosystems is finally being recognised, however, climate change and shifts in water regimes will likely mean degradation and a loss of such services. These are discussed in turn here: deserts, grasslands and savannas, Mediterranean ecosystems, tundra and arctic/Antarctic, mountains, and wetlands[20] (forests are discussed separately in chapter three of this study).

[20] The reference for this section is IPCC, 2007, chapter 4.

2.1.1 Deserts

Deserts are defined by comparative lack of vegetation, which can be increased by both favourable water availability and increased CO_2 levels. Overall, many desert areas are expected to face increased drought and warmer temperatures, punctuated by more episodic precipitation. Thus North American temperate deserts may expand substantially given doubling of CO_2 concentrations, the Kalahari's thin vegetation may be damaged to the point that sand dunes are susceptible to being blown by the wind, which will further suppress rainfall, and one-third of the Sahel may aridify by 2050.

The compensating factor identified in many studies is the fertilising effect of rising CO_2 levels, in C3-limited plants,[21] tending to increase vegetation and reduce desertification. The inverse influences of less water and more CO_2 will be quite site-specific, as well as depending on the degree of warming and climate change. However, on balance the changes in precipitation seem to dominate in most places. Periodic rainfall may promote invasive alien species, opportunistic and fast growing, which then may constitute a fire hazard, particularly when coupled with fertilisation from rising CO_2 levels.

The precarious conditions of life in the desert make the particularly susceptible to change – the Succulent Karoo in South Africa could see 80% habitat loss with as low as 1.5 degree warming, for example. Further, those animals depending on rainfall to breed, such as several bird species, may be severely affected.

2.1.2 Grasslands and Savannas

Grasslands are largely controlled by fire and grazing, but water plays an important role. Increasing precipitation has been shown to increase soil carbon retention, while the opposite is true for a decrease. Some studies have shown variability in rainfall to be an even more significant factor, where an increase in the length of a dry spell led to loss of Net Primary Productivity (NPP), independent of total annual precipitation amounts. While studies of grassland fauna are limited, the predicted decline in summer rainfall in many areas could be disastrous. Much European grassland is in fact grazing land, which is considered separately below.

2.1.3 Mediterranean Ecosystems

Mediterranean climates are found at mid-latitudes around the world, and are commonly biodiverse, coastal, with dry summers and wet winters. They face particular conditions that make them among the most vulnerable to climate change. Water availability is already an important limiting factor. Although variable by region, there are generally predicted decreases in precipitation, and soil moisture. This in turn reduces ecosystem carbon retention. In one study, 60-80% of species in the Southern Mediterranean are not expected to survive warming of 1.8 degrees, while the super-diverse Cape Fynbos in South Africa may lose 65% of its species at 2.3 degree warming.

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[21] Plants can be divided into two categories based on the process by which they assimilate CO_2. In the first step of photosynthesis, C3 plants convert the carbon into a three carbon molecule, whereas C4 plants produce a four carbon molecule. C3 plants are more responsive to CO_2 levels, photosynthesising at a faster rate under increased CO_2 concentrations, whereas increased CO_2 has little effect on the rate at which C4 plants photosynthesise (Gillis, 1993).

2.1.4 Tundra and Arctic/Antarctic Ecosystems

The poles are warming at a particularly high rate. As elsewhere, higher temperatures lead to drying of the land surface and its vegetation, which in the case of permafrost is particularly damaging as moisture is a critical elements to its stability. Unstable permafrost is a major concern given the 500 Pg of methane (CH_4) locked within it that may be released, creating a major positive feedback to warming (see Box 1).

Box 1: methane releases from permafrost

In August 2005 Russian and UK scientists reported that an area of permafrost in western Siberia the size of France and Germany combined was melting. Trapped in the permafrost are an estimated 70,000 million tonnes of methane – which has the equivalent warming potential of 70 times the world's current total annual greenhouse gas emissions. Should a significant quantity of this be released, it could represent one of the "tipping points" climate scientists warn about – massive changes in the process of global warming that are not usually included in standard models.

2.1.5 Mountains

Because of their rise in altitude, mountain ecosystems are quite varied. They can in some cases be like vertical islands, where the only direction for adapting species to move is up – until there is no more space or conditions are too severe. Mountains are experiencing greater than average warming. Among other consequences are a shortened and earlier snow and ice melt, which increases flooding and causes water availability problems at other times of the year. At higher altitudes, the opposite can be a problem, where increased winter precipitation delays the snow melt, causing difficulties for spring migrations. Warmer and drier conditions cause a feedback by increasing evapotranspiration, leading to further drought and subsequent forest dieback, as in the Mediterranean. Local plant species loss in the Mediterranean and Lusitanian mountains is estimated at 62% in 2080 under an A1 scenario[22], with similar impacts for animals and habitats expected.

2.1.6 Wetlands

Inland aquatic wetlands (including depressions with a small catchment, bogs, peatlands) are very vulnerable to changes in water regimes as they rely on external sources of water and are therefore poorly adaptable. Drier conditions may reduce water volumes, increasing the proportional amount of nutrient loading; at the same time, more high-intensity rainfall events may increase nutrient runoff. Combined with higher temperatures this means likely negative impacts like algae blooms. Many species are vulnerable to changes in water availability at various points in their lifecycle, especially in seasonal wetlands.

[22] One of the (relatively high-emission) scenarios developed for the Intergovernmental Panel on Climate Change's Special Report on Emissions Scenarios (see www.ipcc.ch).

Box 2: Peatlands and climate change: the case of Finland

Originally one third of the land area of Finland was covered in peatlands; half of this has been drained for agriculture, converted to forestry or cut for fuel. This amounts to around 5 million hectares lost. About a quarter of Finland's native plant species are found in peatlands, and a third of the country's birds rely on peatland habitats. 53 species are estimated to be under threat due to drainage and peat extraction. 20% of the country's greenhouse gas emissions are due to combustion and disturbance of peat.

The loss of peatlands has a variety of implications. They are unique habitats that support a variety of species specially adapted to them. Draining them also tends to lead to greater fluxes of greenhouse gases, including carbon dioxide, methane and nitrous oxide. It can lead to decreased ground water quality as previously waterlogged peat oxidizes and is flushed into the water supply. Harvesting and burning peat both degrades the habitat and releases CO_2 – growing at a rate of around 1 mm per year, the fuel is non-renewable on relevant time scales.

Finally, peatlands themselves are sensitive to rising temperatures and CO_2 concentrations, meaning they are part of a positive feedback loop between draining, harvesting and combustion that releases CO_2, which causes global warming that leads to further drying of peatlands.

2.2 Impacts on Crop and Grazing Land

Around 40% of the world's land surface is used for crops and grazing land, making these very important to examine when considering climate change impacts, particularly in relation to water. Drought is a major climate threat. Figure 2 shows the mortality associated with drought events in Africa during the 1980s and 1990s.

Date	Location	Mortality and species	Source
1981-84	Botswana	20% of national herd	FAO, 1984, cited in Toulmin, 1986
1982-84	Niger	62% of national cattle herd	Toulmin, 1986
1983-84	Ethiopia (Borana Plateau)	45-90% of calves, 45% of cows, 22% of mature males	Coppock, 1994
1991	Northern Kenya	28% of cattle 18% of sheep and goats	Surtech, 1993, cited in Barton and Morton, 2001
1991-93	Ethiopia (Borana)	42% of cattle	Desta and Coppock, 2002
1993	Namibia	22% of cattle 41% of goats and sheep	Devereux and Tapscott, 1995
1995-97	Greater Horn of Africa (average of nine pastoral areas)	20% of cattle 20% of sheep and goats	Ndikumana et al., 2000
1995-97	Southern Ethiopia	46% of cattle 41% of sheep and goats	Ndikumana et al., 2000
1998-99	Ethiopia (Borana)	62% of cattle	Shibru, 2001, cited in Desta and Coppock, 2002

Figure 2: Impacts of droughts on grazing animals in Africa during the 1980s and 1990s (IPCC 2007, ch. 5).

Some 80% of the world's agricultural land is rain-fed, and nearly all pasture land. About a third of the world's land area is already too dry for rain-fed agriculture, and less than 2% of that amount is suited to cereal crops under irrigation. Therefore, the effect of precipitation changes on agriculture and grazing are of utmost importance to consider. Models show that in general, high latitudes and the wet tropics might see increased runoff, with decreases elsewhere. Some areas currently rain-fed would slip into the category of unsuitable – including the Mediterranean basin. Meanwhile, precipitation extremes (including more severe periodic rainfall) are expected in much of Northern Europe.

Overall, increases in global irrigation need were shown in one study to be +5 to +8%, with regional variation up to +15% (Döll, 2002) and in another to be an average of +20%, which peaks even higher – tending to be more in developed than developing countries (Fischer et al., 2006).

The impact of rainfall changes have to be taken in the context of temperature and CO_2 concentration increases, and the interactions are complex. For example, while higher CO_2 concentrations might be expected to be beneficial in some areas, that benefit is reduced by temperatures rising beyond a certain point, and can be undermined by lack of appropriate precipitation, even though this may in some measure be mitigated by more efficient water use and greater root density. The large-scale implications are "not well understood" (IPCC, 2007).

Drought is not the only danger from precipitation changes. Excesses can also be dangerous to crop yields, and in this respect new research shows that extreme events are likely to be more damaging than previously modelled, through increases in soil moisture, erosion and storm damage.

2.2.1 Impacts on European agriculture

All agricultural systems across Europe are likely to be affected, at least to some extent, by the projected changes in climate in the coming decades (see Annex 1 for a review of the potential effects of climate change on selected arable, permanent crop and livestock systems). This is because rising concentrations of CO_2, increasing temperatures and changes in precipitation affect productivity, the quality and structure of the soil, and the abundance and distribution of pests and diseases. The complex interaction of these factors means that the impact of climate change on agriculture is subject to many uncertainties. However, potential impacts need to be anticipated to develop adaptation strategies and plan mitigation measures to ensure the continuing viability of the sector and to maintain and protect the environmental public goods associated with agriculture.

Climate change may have some positive effects on agricultural production in some regions over the coming decades. In the short term, a rising concentration of CO_2 can stimulate photosynthesis, leading to increases in biomass production in C3 crops such as wheat, barley, rye, potato and rice (EEA, 2004). The response is much smaller in C4 crops such as maize, although rising temperatures may enhance the productivity of these crops. Higher levels of CO_2 also reduce stomatal aperture and density on the leaves of both C3 and C4 plants which causes a reduction in transpiration and a concomitant increase in the efficiency of a plant's use of water (Olesen and Bindi, 2002). These benefits will be particularly pronounced in northern Europe, where higher temperatures coupled with increases in precipitation will serve to prolong growing periods, increase crop yields, decrease the risk of damage by freezing, allow cultivation of new crop species or render new land available for farming (Ecologic, 2007). As climate change advances, however, its negative impacts, such as more frequent winter floods, are likely to outweigh these benefits (EEA, 2004; IPCC, 2007).

Farming systems in southern Europe will be most vulnerable to climate change due to rising temperatures coupled with decreases in both summer and winter rainfall in areas already experiencing water scarcity (IPCC, 2007a). Furthermore, drought conditions alter the structure of agricultural soils, rendering the soil 'strong' and impenetrable to roots, further exacerbating the effects of drought (Whalley et al., 2006). Responses to water scarcity may take a number of contrasting courses, with significant implications for biodiversity.

On the one hand, arid conditions may render agricultural production unsustainable, leading to the progressive marginalisation of the land and possible abandonment (DLG, 2004). On the other, the extent and intensity of irrigation may increase as farmers attempt to keep farming intensively in these areas.

The heat wave of 2003 in Europe (IPCC, 2007)

The combination of temperatures 6 degrees above normal and rainfall 300mm below normal during the 2003 summer heat wave led to significant agricultural losses: drops in maize yields of 36% in Italy and 30% in France; the lowest European wine production in 10 years; overall losses estimated at €13 billion. 650,000ha of forest burned, including 5% of Portugal's total forest area, with an estimated economic impact of over €1 billion.

Even now, southern Europe has the highest demand for water to irrigate crops such as cotton and fruit (IEEP, 2004; Ecologic, 2007) with increases in the irrigable area in France, Greece and Spain of approximately 30% observed between 1990 and 2000. Under drier conditions, more water will be required per unit area, and peak irrigation demands are expected to rise due to heat waves of increasing severity (Oleson and Bindi, 2002). Significant losses in biodiversity have been documented on account of dam building and the conversion of extensive farmland to irrigated fields (EEA, 2005b). In Spain, for example, the habitats of birds associated with cereal steppes have been lost to irrigation (Heath and Evans, 2000).

Changes in climate may encourage the proliferation of agricultural pests and diseases (Kundewicz et al., 2001). Warmer climates provide more favourable conditions for insect pests by enabling them to complete a greater number of reproductive cycles. Warmer winter temperatures may also allow pests, such as aphids, to overwinter in areas where they are currently limited by the cold, thus causing a more extensive and earlier infestation during the following crop season (Olesen and Bindi, 2002). Higher concentrations of CO_2 may stimulate growth and the water use efficiency of weeds, thus altering weed-crop competitive interactions. The efficacy and duration of pesticide control is also affected by environmental conditions, such as temperature, precipitation, wind and air humidity. This may lead to an increase in pesticide use with associated negative environmental effects.

2.3 Opportunities for Enhancement of Water Regimes and Climate Mitigation Regimes through Land and Soil Management

The management of land and soils and their associated ecosystems are inextricably linked to the provision and overall availability of water resources, both groundwater and surface waters. Indeed, water availability is likely to become the major driver of future land use, potentially precipitating significant land-use changes over the coming decades (Cooper and Arblaster, 2007). The capacity of land and soils to deliver adequate water supplies is likely to be adversely affected in areas where water scarcity and droughts occur. The impacts of water scarcity on land and soils are likely to include the degradation of natural environments and associated ecosystem services, desertification in cases of extreme water scarcity, and changes in soil quality and structure linked to declines in moisture levels.

Developing a range of appropriate response options suited to local circumstances will be of vital importance in order to ensure that demand for water resources reflects the availability of water. This section sets out what some of the mitigation and adaptation strategies might be for coping with the effects of water scarcity on ecosystems and the services that they provide. These are dealt with in relation to the main ecosystems.

2.3.1 Water resources

One of the key opportunities in this regard will be the degree to which the availability of water resources can be maintained or enhanced. This will be closely linked to land management and land-use decisions. A combination of adaptation and mitigation measures will be needed to deliver water savings through increased efficiency of water use for existing activities, as well as changes in land-use where current activities are not consistent with the availability of local water resources.

The ratio of water infiltration to soils in comparison to surface water runoff has important consequences for maintaining year-round water supplies. Water scarcity is likely to reduce levels of soil moisture. Where this occurs in combination with high temperatures this may result in the formation of a hard soil layer which will limit infiltration, particularly in areas with poor vegetative cover where rates of surface evaporation of water will be higher. When precipitation does occur, in such circumstances high rates of surface run-off may contribute to flash floods and limit the capacity of land and soils to regulate water supplies more evenly.

As a result land-use responses will also be necessary which may require changes to vegetation cover in the agriculture and forestry sectors as well as in and natural and semi-natural habitats. Ways of improving the capacity of the land to deal with water scarcity include:

- maintenance of vegetative cover, preferably with native species suited to the local conditions;
- coverage of steeply sloping land should be prioritised in order minimise surface runoff and prevent soils from drying out; and
- greater water conservation measures, water pricing, reducing leakages from water supply networks, and effective controls on water abstractions and subsequent water use.

Other measures, particularly relating to agricultural land use, could include the construction of farm ponds and reservoirs which can be used to store water from wetter periods to be used in periods of drought and water scarcity. However, such measures may be expensive and are often associated with potentially adverse environmental impacts including changes to natural river flows and sedimentation (IPPC, 2001). In addition, such options may encourage the continuation of unsustainable water use practices in some areas, delaying the implementation of longer term adaptation strategies.

Recent estimates suggest that there is the potential for achieving water savings of up to 20% in Europe, with the greatest savings likely to be in relation to irrigation (Ecologic, 2007). Adequate water conservation measures will also be needed to reduce consumption in urban areas and in the industrial, tourism and agriculture sectors.

2.3.2 Mountain regions

Mountainous and upland regions have an important hydrological function in terms of water provision. Many important river catchments have their sources in these areas which are often associated with relatively high rates of precipitation. In some regions water from melting snow and ice can help to regulate water flows during the warmer summer months. Increasing temperatures under climate change are likely to have an adverse effect on this function though, resulting in greater stress on water resources and an increased likelihood of water scarcity at certain times of the year.

There are a limited number of adaptation options in mountainous regions in response to the impacts of climate change, including water scarcity (IPCC, 2007). The main opportunities will be linked to management options which maintain and enhance the capacity of such regions to capture rainfall effectively, limit soil erosion, and regulate water flow. Maintaining suitable vegetative cover (including trees, shrubs, scrub etc.), particularly on steeply sloping land, will clearly be important in order to maintain the provision of water services from these areas. Appropriate vegetative cover for the specific circumstances of a particular geographical region, and specific management strategies will be needed in order to maximise the provision of water resources from these mountainous regions. Landscape features (for example hedgerows, fences and terraces) can limit soil erosion and enhance water retention and infiltration and the maintenance of these features, where they exist, will also be important.

2.3.3 Grasslands

Natural and semi-natural grasslands can also have benefits for water resource management through the role they play in soil stabilisation, surface water retention and rates of infiltration. Root structures from such vegetation will enable water to penetrate soils more effectively. In areas where such cover is limited, evaporation rates of soil moisture will be higher and the risk of “soil panning” (the formation of a hard layer in the soil) will be greater. Root structures will help to break up such soil pans where they occur, increasing the infiltration capacity of soils.

Where grassland systems are actively managed, options for addressing the impacts of water scarcity involve improvements to grassland management, such as making adjustments to the cutting and grazing regimes. For example, it is important that grasslands are not grazed too tightly during periods of drought and water scarcity as this will have detrimental impacts on soil moisture and increase the likelihood of surface runoff when rainfall does occur. Grass species which are adapted to drought conditions are mostly suitable with preference given to the maintenance of natural and semi-natural grass species adapted to local conditions.

2.3.4 Wetlands

Wetland and aquatic ecosystems play a vital role in the provision of water resources and therefore the maintenance and (re)establishment of these habitats will be an important strategy for dealing with the impacts of water scarcity. Maintenance of the hydrological function of these habitats will require integrated landscape management as most wetland processes are dependent on catchment-level hydrology (IPCC, 2001).

It is important that wetlands and habitats such as peatlands and upland areas are maintained and not drained as this will reduce the capacity of land and soils to regulate water flows more evenly (Cooper and Arblaster, 2007). In cases where such areas have been drained in the past, there may be opportunities for habitat restoration as this is likely to have significant benefits for water regulation during droughts as well as reducing flood risk during periods of concentrated rainfall.

Peatland has also the capacity to absorb significant net amounts of carbon dioxide from the atmosphere due to high water levels which result in anaerobic conditions. This carbon sequestration can play a role in mitigating the effects of climate change, however, when peatlands are drained this results in net carbon emissions as well as loss of hydrological services. Drained peatland can also represent a fire risk which will put further stress on water resources.

Unsustainable human pressures on water resources can have negative impacts on wetlands through lowing of water tables, salinisation, eutrophication, species loss, all of which can adversely affect the provision of water resources, particularly in the south of Europe (IPCC, 2007). Appropriate responses might include reducing water demand through water savings from all sectors including irrigation practices in agriculture, relocating intensive farming to less environmentally sensitive areas, and restoring riparian vegetation (Alvarez Cobelas et al., 2005).

2.3.5 Biodiversity and ecosystem services

Adaptation responses to water scarcity in terms of management of biodiversity and associated ecosystem services can be aimed at reducing stress on species and ecosystems, although this may be difficult in areas with high population density. Effective responses to these stresses depend on an understanding of likely regional climatic and ecological changes (IPCC, 2007). There is still a great deal of uncertainty as to how adaptation responses by biodiversity to climate change (i.e. changes to species and species compositions) will impact on the provision of hydrological services.

Research into the potential impacts of climate change on biodiversity has been undertaken in research projects, such as BRANCH[23] and MONARCH[24]. However, these projects have tended to focus on how climate change will affect species compositions in the context of climate change rather than how such changes in species composition will affect the provision of ecosystem services.

2.3.6 Agricultural adaptation measures

Until recently, much of the research and policy response to climate change has focused on mitigation and fossil fuel substitution measures to reduce greenhouse gas emissions and to sequester carbon. However, with the adoption in June 2007 of the European Commission’s Green Paper on “Adaptation to Climate Change” this is set to change (European Commission, 2007). The Paper recognises that even if mitigation measures begin to take effect and slow the increase in GHG emissions, climate change is inexorable. Indeed, model experiments show that if all greenhouse gases were held constant at year 2000 levels, a further warming trend would occur in the next two decades at a rate of about 0.1^{o}C per decade (IPCC, 2007).

[23] BRANCH stands for ‘**B**iodiversity **R**equires **A**daptation in **N**orth West Europe under a **CH**anging climate’

[24] MONARCH stands for ‘Modelling Natural Resource Responses to Climate change’.

Actions to cope with a changing climate are thus presented as an indispensable complement to mitigation, rather than as an alternative. There are no explicit measures for agriculture detailed in the Green Paper, although they have been discussed in the Impacts and Adaptation Working Group of the second European Climate Change Programme (ECCP II) charged with exploring options to improve Europe's resilience to climate change impacts (ECCP, 2005).

Because so much of Europe's land is devoted to agriculture, and so much of Europe's water as well (for example, over 90% of overall water consumption in Greece, Portugal and Spain is due to agriculture), agricultural land management decisions will have a significant effect both on the use of water resources and their availability – both of which will be affected by climate change. Options for addressing the effects of water scarcity include improvements to water conservation, changes to crop types and planting dates as well land use changes where current activities are no longer sustainable in terms of water demands.

An important element of water scarcity responses in relation to the agriculture sector, is to ensure that water demand is managed at a sustainable level given local supply and availability. Common responses to water scarcity have historically included increasing the intensity and volume of water used for crops, particularly in southern Europe, with evidence that this is already underway. However, this carries significant adverse consequences for the natural environment (Cooper and Arblaster, 2007). For example, increased rates of water abstraction have led to lowered water tables and river flows, the disappearance of wetlands, damage to terrestrial and aquatic habitats upstream and the salinisation and contamination of groundwater (Baldock et al, 2000).

Options to address increases in water scarcity in agriculture include:

- Efficiency improvements to irrigation management by making the timing and volume of water distribution more precise. Within the agriculture sector efficiency gains, in terms of water use per unit area, of up to 50% are thought to possible through switching irrigations technologies from gravity to drip or sprinkler feed systems. This is thought to be a viable option for most crops including citrus plantations, vineyards, and deciduous tree crops (EC 2007a).
- Conservation tillage, the practice of leaving some of the previous season's crop residues on the soil surface, minimises soil disturbance and may protect the soil from wind and water erosion and retain moisture by reducing evaporation and increasing the infiltration of rainwater into the soil (IPPC, 2001). This practice is not suitable, however, in large parts of Europe where fields are small and sloping, because it requires heavy machinery.
- In areas where it is no longer desirable to maintain cropping due to inadequate water supplies, a mitigation option could be to establish native varieties of forests or grassland, or to allow natural regeneration. This could enable the maintenance of beneficial ground cover whilst reducing water demand. This option may be most appropriate in the upper reaches of river catchments and peatlands restored to render them more capable of retaining water. High levels of water abstraction will not be sustainable in arid areas, and as a result agricultural production may need to become more extensive and less water demanding, or ultimately even be abandoned (Cooper and Arblaster, 2007).

- Small scale water conservation measures could be implemented, for example, collecting water from farm buildings for use on the farm and constructing on-farm reservoirs to supply water to the farm (Cooper and Arblaster, 2007).
- Other options include changing crop types and management practices to one which are less water demanding and better adapted to climate conditions under water scarcity. Some crops use low amounts of water and are more resilient to water scarcity. For example, sorghum is more tolerant of hot and dry conditions than maize (IPCC, 2001). In central Europe, optimal land use may involve increasing the area of winter wheat, maize and vegetables and decreasing the area of spring wheat, barley and potato which will be less suited to increased temperatures and lower water availability (Olesen and Bindi, 2002). In the south of Europe, short season cultivars that are planted earlier are more likely to reach maturity in advance of the arrival of extreme high summer temperatures, thus avoiding injury from heat and water stress (Maracchi et al., 2005). As high levels of water abstraction becomes unsustainable in arid areas, agricultural production may become less viable and ultimately abandoned. The rice sector in Spain, Portugal and Greece is particularly vulnerable (Agra Europe, 2007). Water availability is likely to become the major driver of future land use, precipitating land use changes.
- Biotechnology offers the possibility of developing varieties of crops and trees that are more tolerant to heat and water stress and different diseases and insect pests (see, for example, Laporte et al., 2002).

In theory, many of the impacts on the productive capacity of the agricultural sector can be addressed. However, some of the more extreme measures would precipitate changes to land use and structural changes, both in terms of the landscape and farming systems. All of these carry implications for the natural environment as they would disrupt the relationships between farmland species, their habitats and land management practices established over long periods of time (Bignal and McCracken, 1996).

Crop substitution would, for example, remove habitats for certain farmland species and potentially create habitats for others, thus changing the balance of species found in a particular area. Many of these species are already under threat, as habitat loss is further exacerbated by climate change. These effects have been demonstrated in the MONARCH project, for example, which showed that for those species[25] modelled, a majority are likely to experience changes in the range and / or extent of their suitable habitats by 2020, 2050 and 2080 (see Walmsely et al., 2007). Under such circumstances, there will be a need to develop and maintain an interlinked network of habitat and ecological networks to ensure species survival, as is the goal of the Natura 2000 network (Opdam and Wascher, 2004; Chambers and Ball, 2007). Some of the adaptation measures will constitute a significant challenge for public policy as they will require significant investment and will cause shifts in the comparative advantages of regions and, thus, in their competitiveness.

[25] Ones included in the UK biodiversity action plan (BAP), see http://www.ukbap.org.uk/.

2.4 Agricultural mitigation measures

Whilst the agriculture sector is a prime emitter of GHGs, there are various measures that can be taken to mitigate GHG emissions, to sequester GHGs from the atmosphere and to store them in terrestrial carbon sinks.

Climate change mitigation encompasses all activities which are designed to slow or reduce the total climate change effect. Specifically, mitigation is defined as an anthropogenic intervention to reduce the sources or enhance the removal of greenhouse gases through sinks (IPCC, 2002). The agriculture sector has the potential to carry out a range of mitigation activities. These include: manure/biosoil management, for example, a reduction in ammonia and methane emissions could be achieved by reducing the surface area of manure exposed to the air through regular washing or scraping of the floor in animal housing; methane emissions can be reduced from slurry based manure systems by increasing the manure storage temperature; livestock management, for example, modifying livestock feeding strategies such as adjusting the feed composition to decrease the amount of nitrogen excreted to reduce nitrous oxide emissions; land cover and land use change; agro-forestry; crop management; tillage/residue management; nutrient management; water management; grazing land management/pasture improvement; management of organic soils.

The remainder of this section focuses on soil carbon sequestration as a climate change mitigation strategy. This is because, with the exception of bioenergy, covered in the following section, a large proportion of the mitigation potential of agriculture arises from soil carbon sequestration (IPCC, 2007) and its application carries implications for future trends in land management and use.

2.4.1 Soil Carbon Sequestration

Soil carbon sequestration implies the removal of atmospheric CO_2 by plants and the storage of fixed carbon as soil organic matter. Under Article 3.3 of the Kyoto Protocol, which is mandatory, emissions and removals from afforestation, reforestation and deforestation since 1990 are counted towards the emissions targets of Annex 1 countries[26].

Article 3.4 makes provision for the optional inclusion of emissions and removals from additional land management activities relating to the improved management of forests, cropland and grazing land, land restoration and re-vegetations. Carbon sequestration has significant potential in the short to medium term to offset CO_2 emissions and yet the policy steer has been relatively weak in a European context where the focus has been on emissions reductions as the primary mechanism to mitigate climate change[27].

[26] Those industrialised nations that signed up to the Kyoto Protocol.

[27] In contrast to the US, where the Bush administration and Congress, although not ratifying the Kyoto Protocol, have supported the use of agricultural soils to sequester carbon through domestic farm policies and have funded major research initiatives to support agricultural sequestration under the framework of the 2002 Climate Action Plan (Young et al., 2007).

This reticence stems, in part, from a perception that carbon sequestration is a risky, and therefore perhaps unviable, mitigation strategy in the long term. Concern has been articulated with regard to uncertainty over the rates of accumulation, the permanence and measurement of carbon stocks (Lindner and Karjalainen, 2007), and the complexity of the interaction between indirect and natural factors which impact, in unpredictable ways, on the scale and direction of soil carbon fluxes (Smith, 2005). Specifically, the environmental lobby feared that a focus on sequestration may divert attention away from the pursuit of a net cut in industrial, domestic and other emissions – a more sustainable trajectory. Whilst these objections are rationally sound, the shortcomings of carbon sequestration as a climate mitigation strategy are tempered by the provision of substantial ancillary environmental and economic benefits, including an improvement in soil structure (see Thematic Strategy for Soil Protection, European Commission, 2006a), and reductions in flood risk via peatland restoration. These additional public benefits render it an important area of activity and policy intervention.

Soils can either be a source or a sink of carbon[28]. To maintain the role of soils as a net sink, the rates of depletion of carbon from the soil need to be minimised, and its absorption capacity, and thus its sequestration potential, maintained or enhanced. The global potential of Soil Organic Carbon (SOC) sequestration has been estimated by Lal (2004) to be 0.9 +/- 0.8 Pg C/year, which equates to between one quarter and one third of the annual increase in atmospheric carbon levels, measured at a rate of 3.2 +/- 0.1 PgC/year. This figure for sequestration potential is widely quoted, however, the actual potential may be significantly lower[29]. Soil carbon content depends on the rate of addition of carbon from plant growth – net primary productivity – against the rate of removal of carbon through the decomposition of organic matter, leaching and other soil processes such as disturbance and erosion. As such, the sink potential is highest when there are high crop yields, minimal levels of soil disturbance and low rates of decomposition of soil organic matter. Low rates of decomposition tend to occur in those countries with low temperatures and wet conditions. Each of these factors, however, is sensitive to changes in land use, historic and present management, climatic conditions and other variables (Freibauer et al., 2004) so there is a wide variation in the sequestering potential of soils in different regions.

In addition to the variables mentioned above, there are a number of management options – Recommended Management Practices (RMPs) – which increase the total organic carbon content of the soil, and thus the soil's sequestration potential. The most promising approaches are summarised below, although each carry implications for farm profitability and could be constrained by the availability of suitable land and other resources.

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[28] There is a broad consensus that the atmospheric concentration of carbon is increasing at a rate of 3.2 +/- 0.1 PgC/year based on figures from the 1990s. Of this, 6.3 +/- 1.3 PgC/year are from fossil fuel combustion and cement production, and 1.6 +/- 0.8 PgC/year are from land use change, including soil cultivation. A significant proportion is subsequently reabsorbed by sinks including the oceans, 2.3 +/- 0.8 PgC/year, and the territorial sink, 2.3 +/- 1.3 PgC/year (Lal, 2004; Smith, 2005).

[29] Other estimates differ widely, suggesting that the realistically achievable potential may be significantly lower (Smith, 2004). Freibauer et al., (2004), for example, have estimated that agricultural soils in the EU-15 have the potential to sequester up to 16 – 19 Mt C / year during the first Kyoto commitment period (2008 – 2012), which is less than one fifth of the theoretical potential and equivalent to 2% of European anthropogenic emissions. Smith et al., (2000) estimated that a realistic potential for carbon mitigation on UK agricultural soils is 10.4 Tg C/year, which is about 6.6% of the UK's CO_2 emissions in 1990.

All of the practices identified could be stimulated through policy intervention, within the existing framework of the European Agricultural Fund for Rural Development (EAFRD)[30] and its potential successor, and cross compliance, but would require a significant adjustment in the objectives that rural development measures seek to address.

Measures for increasing soil carbon inputs centre on enhancing net primary productivity, stimulated through judicious nutrient management and methods of livestock management. An adequate supply of nitrogen and other essential nutrients in the soil can enhance biomass production under elevated CO_2 concentrations, in turn enhancing the SOC pool. The amount of carbon in the soil can also be increased by the preferential use of animal manure, crop residues and sewage sludge, and the incorporation of cover crops in the rotation cycle. Measures to minimise the depletion of the SOC pool focus on reducing soil disturbance and include reduced or zero tillage systems on cropland[31] and the growth of perennial crops in the place of annuals.

The organic carbon content of the soil will be increased by the conversion of conventional agriculture to other land uses with high carbon inputs and low levels of disturbance, such as natural regeneration and permanent set aside (Guo and Gifford, 2002). Included in this suite of measures is the conversion of cropland to grassland or pastures, which is widely cited as the most effective carbon mitigation option (Schuman at al., 2002; Smith, 2004).

The maintenance or re-flooding of peatlands is also an important carbon sequestration measure. This is because peatlands absorb significant volumes of carbon from the atmosphere and emit very little in turn due to the slow decomposition of peatland plants. In spite of the important role played by peatlands as a net carbon sink, there has been a dramatic decline in peatland cover across western Europe over the last century. For example, in the United Kingdom and Ireland over 90% of raised bogs have been lost. More than 50% of the original peatland resource remains in only six countries in the European continent, Russia, Latvia, Liechtenstein, Norway, Sweden and the Ukraine (see http://www.peatlandsni.gov.uk/formation/euro.htm). Peat is threatened by drainage, burning, grazing and climate, all of which lead to releases of carbon. Drainage is associated with environmental degradation including increased flood risk.

Whilst it is desirable to encourage carbon sequestration activities, the carbon sequestration potential of the soil is not limitless, and even with proactive management, it does not have the capacity to absorb increasing volumes of carbon in perpetuity. A point is reached at which the sink strength is decreased to zero and there is no further uptake of carbon from the atmosphere, with the exception of peat bog which will continue to accumulate organic matter, and thus sequester carbon, indefinitely if in good condition. This is referred to as sink saturation (Watson et al., 2000).

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[30] The EAFRD was created as a single fund for rural development for the European Member States under European Commission Regulation 1698/2005 on support for rural development by the European Agricultural Fund for Rural Development (OJ L277/1 21.10.2005). This Regulation provides Member States with a framework for the targeting of support within rural development programmes running from 1 January 2007 to 31 December 2013.

[31] As organic matter contains nitrogen as well as carbon, increasing the soil organic carbon content also provides more substrate for nitrogen loss by leaching and N_2O emission. For practices that potentially increase denitrification (for example, no-till), these N_2O losses can be substantial and may have a significant impact on the overall GHG mitigation potential (Smith *et al*., 2001).

The time taken for sink saturation is highly variable, but for soils in a temperate location, such as Europe, the period to reach a new equilibrium after a land use change is around 100 years (Smith, 2005). Furthermore, the carbon sequestered in agricultural soils is not stored permanently, and the carbon sequestering activity needs to be maintained even after the sink is saturated. Indeed, if a land management or land use change is reversed or discontinued, the carbon which has been accumulated is lost at a rate more rapid than the one at which it was accumulated. As such, management regimes, once established, should not be revoked. On privately owned land, this carries significant implications for the "freedom to farm" of future generations and, if it were to be effective, implies the setting up of a covenant which is binding on the current and subsequent landowners[32]. It is unlikely, therefore, that arrangements of this type will apply over large areas of land unless they are made a management condition of long term environmental set aside, or Ecological Priority Areas (Cooper *et al.*, 2007 in prep).

2.4.2 Mitigation through bioenergy crops

Agriculture and forestry have the potential to produce significant volumes of renewable energy from biological sources and thus to displace the utilisation of fossil fuels. In theory, increases in the volume of bioenergy produced will reduce greenhouse gas emissions and thus contribute to meeting obligations under the Kyoto Protocol and wider climate change objectives.

In March 2007, the European Council approved the Commission's Energy Package, which will lead to the introduction of a mandatory target for renewable energy use of 20% of the total energy mix. In addition, a minimum mandatory target for biofuel utilisation of 10% of overall consumption of petrol and diesel in transport by 2020 was set[33]. To meet the 2020 targets, it is indicated that much of the growth in renewable energy would come from the increased use of bioenergy for the production of heat and electricity, as well as biofuels for transport. The 10% biofuels target exceeds that which is technically possible through current levels of production of blended fuels. It is also unlikely that Europe has the capacity to supply its own needs, at least if much of the demand is supplied through first generation food crops, and imports of feedstocks are expected to rise in the future. It is thus important that the Community's policy is integrated with climate policy and is developed in a coherent way in order to provide solutions that lead to the greatest reductions in GHG emissions.

Production chains

Solid, gaseous or liquid forms of energy can be produced from conventional agricultural crops capable of high biomass yields, for example, cereals and sugar beet; oilseed crops, such as oilseed rape, linseed, field mustard, hemp and sunflower; the organic residues and wastes from food crops, such as cereal straw and livestock waste; (Tuck et al., 2006); from the food industry and from industrial and household waste (EEA, 2006).

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[32] The Queen Elizabeth II National Trust in New Zealand has set up a system of open space covenants to protect natural features and habitats. These are legally binding protection agreements entered into between the Trust and landowners, and which are registered on the title of the land. The covenants are voluntary, but once in place, they are binding on the current, and all subsequent landowners (see www.nationaltrust.org.nz).

[33] These targets supersede, to a significant degree, those specified in the Biofuels Directive (2003/30/EC) which set indicative "reference levels" for biofuel use in each Member State. Reference values for the targets were set at 2% at the end of 2005, rising to 5.75% by the end of 2010.

The cultivation of high yielding, non food crops such as *Miscanthus*, Short Rotation Coppice (SRC) and *Eucalyptus*, dedicated to the generation of bioenergy has emerged as a more recent phenomenon. Each of these feedstocks can be fed into a range of bioenergy production chains to produce heat, electricity and liquid transport biofuels. Some of the key production chains include:

- The production of electricity and/or heat from the combustion of woody biomass, such as the by products of forestry operations, including harvesting residues and sawdust, straw, Short Rotation Coppice (SRC), *Miscanthus* and *Eucalyptus*.
- The production of electricity and/or heat from the combustion of biogas - primarily in the form of CH_4 - generated from the anaerobic digestion of agricultural residues such as livestock wastes, maize or grass silage.
- The production of biodiesel, or Fatty Acid Methyl Esters (FAME) - a first generation liquid biofuel[34] - through the esterification of vegetable oils from crops such as oil seed rape, linseed, field mustard, hemp and sunflower.
- The production of bioethanol or Ethyl Tertiary Butyl Ether (ETBE) - a first generation liquid biofuel - from the fermentation of plant biomass, specifically carbohydrates in the form of sugars, starch or cellulose sugar of conventional agricultural crops, such as cereals and sugar beet. This is a substitute for, or additive to petrol.
- The production of second generation liquid biofuels such as ethanol, Dimethyl Ether, Substitute Natural Gas or Fischer-Tropsch diesel through the, as yet mainly experimental, processes of gasification or enzyme treatment of agricultural by products such as straw, *Miscanthus* and SRC, which are not yet grown on a commercial scale, although the crop technology is well advanced.

Land Use Implications

In 2005, an estimated 3.6 million hectares of agricultural land in the EU-25 were allocated to the production of feedstocks for the generation of heat, electricity and liquid biofuels[35]. A majority of the land was used for the production of oil seed crops for biodiesel (83%); with a further 11% for wheat and sugar beet, for bioethanol; 4% for maize for biogas production; and 2% for short rotation forestry.

Europe is a major producer of biodiesel, accounting for 90% of the total production worldwide (JNCC, 2007). Its production increased more than 20 fold between 1994 and 2005, and in 2005, it accounted for 3.1% of total renewable energy production (EEA, 2006).

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[34] Liquid transport biofuels are often referred to as “first” and “second generation” biofuels. This distinction stems from differences in the feedstock, the conversion technology and their commercial viability at the present time, rather than a difference in the end product. Bioethanol, for example, can be derived from both first and second generation biofuel production chains.

[35] Support for farmers growing energy crops is provided under the EAFRD Regulation 1698/2005 (2007-2013). Establishment grants of up to 50% are available for permanent crops and the Energy Crop Supplement of €45 per hectare is available in all Member States of the EU-27. The maximum area of land eligible for support under this scheme is two million hectares which excludes all set aside land. Silcock and Lovegrove (2007) estimate that six million hectares of set aside land is currently under production of non food crops, including those for bioenergy and industrial use.

This is driven, in part, by the widespread use of diesel in Europe, whereas it is less prevalent in other markets, such as the US. In 2006, approximately 17 million tonnes of rapeseed were produced in the EU, of which a large majority was grown in five Member States: Germany, France, the UK, Poland and the Czech Republic (Ollier, 2006). Of this, between 60 and 70% served as a feedstock to provide rapeseed oil methyl ester (RME) for liquid biofuels. Reflecting an ever increasing demand for biodiesel, production is projected to increase to 20 million tonnes in 2010-2015.

Approximately 69 million tonnes of oil equivalent (Mtoe) of the EU's total primary energy consumption is currently met from biomass sources (EEA, 2006), just over a quarter of that which would be required to meet the EU's mandatory target for renewable energy use of 20% of the total energy mix. It has been calculated that for this target to be met, approximately 250 Mtoe will be required from primary biomass potential, depending on assumptions about total energy consumption, increases in other renewable energy sources and the end use of the biomass (EEA, 2006), although it is unlikely that this will all come from domestic production.

Various projections have been made of the land use implications of a growth in the production of bioenergy within the European Union. In the Biofuels Progress Report (European Commission, 2006), the Commission calculates the area of arable land that would be required in 2020, given a range of assumptions about the biofuel share of total road fuel demand. It is estimated that in 2020, the total area of arable land required for biofuel production will be between 7.6 million and 18.3 million hectares, equivalent to approximately 8% and 19% respectively of total arable land in 2005 if we assume a biofuel share of total road fuel demand of 7 and 14%. Under the latter scenario, of the 18.3 million hectares of arable land required, they estimate that 7.5 million hectares would be arable land formerly used in the production of food, 7 million hectares would be former set aside land, and 4 million hectares would be derived from an expansion of the area under arable production.

Another study has investigated the land potential for biomass production in individual Member States with the results suggesting a concentration in the cultivation of bioenergy crops in certain areas of Europe (Thran at al., 2005). The land potential for biomass production in France, Germany, Denmark, Ireland, the Baltic Member States and Hungary is high due to the availability of large areas of high yielding agricultural land. In Poland, significant areas of fallow land are expected to be available and Spain has a high land potential due to a declining agricultural population, although the cultivation of bioenergy crops in Spain may be significantly threatened by climate change in the future[36].

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[36] Tuck at al., (2006) assessed the impact of climate change on the potential future distribution of bioenergy crops under each of the IPCC SRES scenarios. In line with predicted trends in conventional crops, the potential distribution of temperate oilseeds, cereals, starch crops and solid biofuels is predicted to increase in northern Europe by the 2080s, due to increasing temperatures, and decrease in southern Europe (Spain, Portugal, southern France, Italy and Greece) due to shortages in the availability of water. All models indicate that most of southern Europe will be vulnerable to climate change and the growth, in these regions, of all temperate oilseeds, starch crops, cereals and soil biofuel crops is expected to be seriously impaired.

Italy, the Netherlands, Belgium, Luxembourg and Greece have a low land potential for biomass production. In the UK, land potential for further bioenergy production is also low, based on assumptions about the rate of population growth.

These shifts in agricultural production and land use are reasonably fluid, however, as the feedstocks for bioenergy are expected to change over time. In 2010, 40% of the bioenergy from agriculture in Europe is projected to come from conventional biofuels produced from oil seed rape and cereal crops. Over time, demand for these crops is expected to decline as they are replaced by more efficient feedstocks such as SRC and *Miscanthus* (EEA, 2006).

Biodiversity Impacts

The impact on biodiversity of the cultivation of bioenergy crops will depend, in part, on their pattern of distribution within landscapes. The biodiversity impact is likely to be more favourable if bioenergy crops are dispersed over a sizeable area and a significant number of farms, forming a mixed cropping pattern. In contrast, the concentration of one type of bioenergy crop in large blocks, forming dense areas of monoculture, will lead to a simplification in the structural diversity of the landscape, with considerable negative impacts on biodiversity (Baudry et al., 2000; McCracken and Klockenbring, 2007).

Biodiversity impacts will also depend, to a large extent, on the quality of the land use or habitat that the bioenergy crops replace. If more marginal, extensively managed land is replaced by bioenergy crops, overall biodiversity effects will be negative. The ploughing up or intensification of extensive grassland would generally lead to a loss in biodiversity value and a release of soil carbon (Schelhaas et al., 2007a). Conversely, where bioenergy crops contribute to land use heterogeneity, for example, by introducing an arable system into an area dominated by grassland, biodiversity benefits may occur (McCracken and Klockenbring, 2007).

If, in the short term, the bioenergy targets stimulate an increased production of crops, such as wheat and oil seed rape for first generation biofuels, negative impacts on biodiversity are likely to result. Owing to the questionable economics of conventionally produced biofuels, there is strong pressure for high yields and thus these crops are likely to be produced in an intensive manner. Nutrient input is generally high for wheat, maize, oilseed rape, and sugar beet, in particular, has a relatively high impact on soil structure as it requires the use of heavy machinery during harvesting (EEA, 2006).

It is difficult to assess the biodiversity impacts of growing woody perennial crops, such as SRC and *Miscanthus,* since commercial scale plantations are not yet widespread in Europe. In comparison with conventional arable crops, however, they generally have less impact on soil structure and compaction, since after establishment no further ploughing is required and they use nutrients economically, resulting in low fertiliser requirements (Schelhaas et al., 2007a).

There is some evidence that large scale SRC plantations can provide benefits for some taxonomic groups, for example, bird species typical of rank herbaceous vegetation, scrub and young woodland, as well as butterflies and flowering plants (Anderson and Fergusson, 2006). The bird community associated with SRC would be expected to change in response to the cycle of growth and subsequent harvest of the crop.

Densities of some bird species, such as tits, thrushes and warblers, characteristic of woody/scrub habitats may increase, while bird species preferring open habitat, such as skylarks and wagtails would decrease as the crop became established (Anderson et al., 2004). It is unlikely that SRC will confer benefits on farmland bird species of biodiversity concern as they are typically more closely associated with open farmland habitats. On the other hand, SRC crops provide an important opportunity to reduce the problem of nutrient run off when planted along buffer zones adjacent to water bodies (IEEP, 2004).

Literature is scarce on the links between growing perennial grasses for bioenergy and biodiversity since this is still in the early stages of commercial development. Hope and Johnson (2003) suggest that given the structure of the crops – tall, high density grasses – they will provide poor habitat for arable plants, birds and large mammals, although they may benefit ground dwelling invertebrates and small vertebrates.

2.5 The contribution of the Common Agricultural Policy to the Climate challenge

The European Union does not have a land use policy. It does possess, however, a well established agricultural policy with the capacity to influence land use decisions on a European scale. As energy and agricultural policies operate increasingly in the same domain, new questions about the relevance of the current CAP objectives, the policy machinery required and the budget available for the sector in the longer term arise. These will be more prominent in the debate over policy beyond 2013. The potential for unencumbered thinking about the future of policy relating to agriculture, climate and land use in Europe is increasingly apparent.

Climate change has entered the lexicon of the CAP but has made relatively little impact on the policy measures it contains. The principal focus has been on incentives for growing energy crops, where the objectives have been wider than the mitigation of greenhouse gas emissions or climate change, reflecting a concern to diversify farm incomes, for example. There has been little attention given to mitigation from carbon sequestration or delivering adaptation as priorities for agricultural policy. In the second Pillar of the CAP, concerned broadly with rural development, there are no dedicated measures responding to the climate challenge. There is, on the other hand, a clear instruction to the Member States in the Strategic Guidelines that their rural development programmes should address Community priorities, one of which is climate change. In this sense, the process of absorbing a new climate dimension into the CAP is in its infancy.

By contrast, the combination of climate and energy policy is coalescing into a force that could drive agricultural production and longer term structures in the countryside, either operating alongside more traditional rural policies, or even overwhelming them. European energy policy, accompanied by national measures of varying degrees of vigour, could effectively incentivise and support aspects of arable production over a sustained period of years.

If demand and price levels for arable crops moved high enough there could be negative consequences for biodiversity, water quality and carbon sequestration. For example, the case for continued direct payments for arable farms could be much weakened if farms were more profitable and land prices correspondingly higher. Loss of permanent grassland, which is valuable from a biodiversity perspective, could occur as it is converted to arable.

It will be important to recognise that, beyond energy crops, there are many possible mitigation options to pursue. Some of the most interesting are those which offer multiple benefits, above and beyond reducing emissions. For example, the re-flooding of oxidised peat soils in selected locations could contribute to soil conservation, climate and biodiversity goals. A cross cutting approach to policy based on a revised conception of rural priorities could both feed through existing policies, such as Pillar Two of the CAP and the Nitrates Directive, and inspire new initiatives. It would sharpen the focus on land use issues and priorities in Europe without requiring a significant shift in responsibilities from the local and national level.

Much less attention has been paid to the need to manage environmental stress arising from the impacts of climate change. This includes pressures on biodiversity, the need to facilitate the migration of species, changes in traditional landscapes, flood management and reduction in rural water supply. Investment will be required to mitigate negative impacts and manage adaptation in the rural environment. These pressures could be increased by inappropriate large scale production of bioenergy crops and any intensification of food production.

From this perspective, the response to climate change in the rural environment does not need to be a remodelling of the CAP. A series of specific and targeted measures, informed by a land use and environmental perspective and supported by an adequate budget, would respond to new and sometimes unpredictable requirements. Certain of these measures will fall within conventional agricultural policy, many outside it. Links between farming, energy and environmental policy perspectives need to be strengthened and institutional relationships adjusted accordingly.

The logic of a more carbon centric rural policy is to have a greater focus on resource management in the countryside both in agriculture and forestry. For example, commodity production can be viewed from a new perspective, reflecting the role of annual crops, woodier crops such as short rotation coppice and forestry in an overall carbon budget. Soil management becomes a more important issue than previously and the capacity to monitor and even steer land use changes becomes a European, as well as a local, concern.

3 FORESTS, DEFORESTATION AND CLIMATE CHANGE

3.1 Introduction and Background

Increasing rates of deforestation and land use change especially in developing countries have raised international awareness on the need to protect forests. Forests provide a wide range of ecosystem services that humanity benefits from but usually does not pay for. Apart from carbon storage and sequestration, these services include water storage, rainfall generation, climate regulation, biodiversity, soil stabilisation and more.

Destruction of forest ecosystems and other forms of land clearing and land use change lead to enormous carbon emissions into the atmosphere thereby boosting climate change. Emissions from deforestation alone are estimated to account for 25% of all the anthropogenic greenhouse gas (GHG) emissions (Skutsch et al., 2007). Since causes of deforestation and land use change are very complex, current mechanisms to combat the loss of forests have mostly failed. Instead, forest degradation worldwide is continuing, additionally driven by growing demand for food due to population growth and changing consumption patterns in emerging economies as well as increased use of biomass for bioenergy. Globally, forest losses increase greenhouse gas emissions. Regionally, they can lead to micro-climatic changes, biodiversity losses, and changes in the water regime.

With forest being currently at the very centre of the international debate on climate change their important role in the world carbon cycle and for climate protection has been recognised by the international community. Parties of the 13^{th} conference of the parties of the United Nation Framework Convention on Climate Change (UNFCCC COP 13) in December 2007 in Bali agreed to include forest-based carbon stocks and deforestation-based GHG emissions in the formal negotiations leading to a post-Kyoto instrument for reducing emissions and implementing the UNFCCC. Different approaches of Reducing Emissions from Deforestation and Degradation (REDD) will be discussed in the light of a post-Kyoto climate regime. Major parts of the discussion will concern possible ways of accreditation of carbon sequestration measures under national accounting systems for carbon credits and respective funding opportunities.

This part of the study will first give a general overview on forests and their role in the world climate. Furthermore, it will highlight important ecosystem services that can be derived from forest ecosystems with a special focus on their function for small and large scale water cycles and microclimatic conditions as well as their role for the preservation of biodiversity.

Chapter two will discuss the major threats of forest ecosystems, giving a comprehensive overview of the numerous and complex drivers and underlying causes leading to deforestation and degradation. The extent of impacts on forest ecosystems and ecosystem services including respective effects on climate change, biodiversity and society will be described in chapter three.

The study ends with a selection of possible ways forward to combat forest degradation in the future taking into account policy options as well as economic incentives which are currently discussed within UNFCCC.

3.2 Forest Ecosystem Services

Ecosystems provide a wide range of services that are critical to human well-being. Such "ecosystem services" have become part of substantial research and assessment studies in the recent years culminating in the Millennium Ecosystem Assessment in 2005. They include provisioning, regulating and supporting services as well as cultural services. Food products, fresh water and genetic information used for biotechnology are typical examples for provisioning services, while regulating services include crop pollination, maintenance of hydrological cycles, flood and drought mitigation, erosion protection, and air and water purification. In the context of forests in connection to climate change, regulating and provisioning services are in the core of interest (see Table 1). Beside the crucial role of ecosystem services and functions for human well-being including the basic material needs for a good life, health, good social relations, security, and freedom of choice and action, they are also a substantial basis of economic activity and employment (MEA, 2005a). The economic value of timber provision alone including all downstream benefits and markets were estimated to account for around 400 billion $ in 2000 (MEA, 2005a). However, only a portion of the total economic benefits provided by an ecosystem makes its way into statistics, and many of these are misattributed (the water regulation benefits of wetlands, for example, do not appear as benefits of wetlands but as higher profits in water-using sectors). Moreover, many ecosystem services (most regulative functions such as water purification or cultural services like aesthetic values) do not pass through markets because no countable value in form of prices can be detected or even attributed. Consequently, overall benefits of ecosystem services are underestimated. For example, one study for eight Mediterranean countries cited in MEA (2005a) which examined the marketed and non-marketed economic values associated with forests found that timber and fuel wood generally accounted for less than a third of total economic value in each country. Such underestimation often leads to the attitude that ecosystem services are for free which opens the door for their overexploitation or degradation.

Table 3: Forest Ecosystem Services in context of climate change and water (Source: MEA, 2005)

TYPE OF ECOSYSTEM SERVICE	CONTEXT
Provisioning Services	
Fuel (biomass for combustion and for production of biofuels)	**Climate Change**
Fresh water	**Water**
Regulating services	
Climate regulation (e.g. temperature and precipitation, carbon storage)	**Climate Change and Water**
Water regulation (e.g. flood prevention, timing and magnitude of runoff, aquifer recharge, control of droughts etc.)	**Water**
Water purification and waste management	**Water**

3.2.1 *Forests and climate*

The biophysical relationship between forests and climate rests on three coupled exchanges with the atmosphere: carbon, water and radiation (Gurney, 2007).

Forests play a major role in climate mitigation strategies through carbon sequestration and the provision of products substituting fossil energy and materials. Furthermore, forests contribute significantly to regional climate regulation and to continuous water supply in large and small scale water cycles. These regulating services of forests including their alleviating functions can be essential for adaptation strategies to climate change effects.

Carbon Storage

As one of the biggest natural carbon storage capacities forest ecosystems function as an important carbon sink in the global carbon cycle. The photosynthesis of vegetation is the only process that removes large amounts of CO_2 from the atmosphere. Of the approximately 8 billion tons of carbon emitted each year by fossil fuel burning, deforestation, and other sources, about 40% accumulates in the atmosphere and approximately 30% is absorbed by the oceans. Scientists believe that terrestrial ecosystems, especially trees, take up the remainder. However, uncertainties remain over the question of how much carbon is captured by boreal and temperate forests compared to tropical rainforests. American scientists recently claimed that some 40% of the carbon dioxide previously assumed to be absorbed by northern forests is instead taken up in the tropics. Their results even underscore the major role intact tropical forests play in absorbing carbon dioxide.[37]

The FAO (2005) estimates that global forest vegetation stores 283 Gt of carbon in its biomass, and an additional 38 Gt in dead wood, for a total of 321 Gt. Huge components of carbon stocks are not only found in vegetation of forests but also in the soil. Soils (down to 30 cm) and litter contain 317 Gt of carbon according to the assessment of the FAO.

On average, aboveground biomass and dead wood account for 44 and 6% of total forest ecosystem carbon respectively, while soils and litter contribute approximately 46 and 4% respectively (FAO, 2005). In sum, the total carbon content of forest ecosystems calculated for the year 2005 is 638 Gt of carbon, which is more than the amount of carbon in the entire atmosphere.

As already pointed out, there are significant differences in carbon stock capacities between regions. Due to different climate and physical conditions carbon stocks in forest biomass reach the highest values per hectare in Central and South America (with Brazil having the largest growing stock, with 81 billion m^3 or 19% of the world's total*)* and Western and Central Africa, while East Asia, Northern Africa and Western and Central Asia have the lowest values.

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[37] See: National Center for Atmospheric Research (2007, June 22) Scientists Close In On Missing Carbon Sink, *ScienceDaily*, Retrieved 12 December 2007, from http://www.sciencedaily.com /releases/2007/06/070621140805.htm

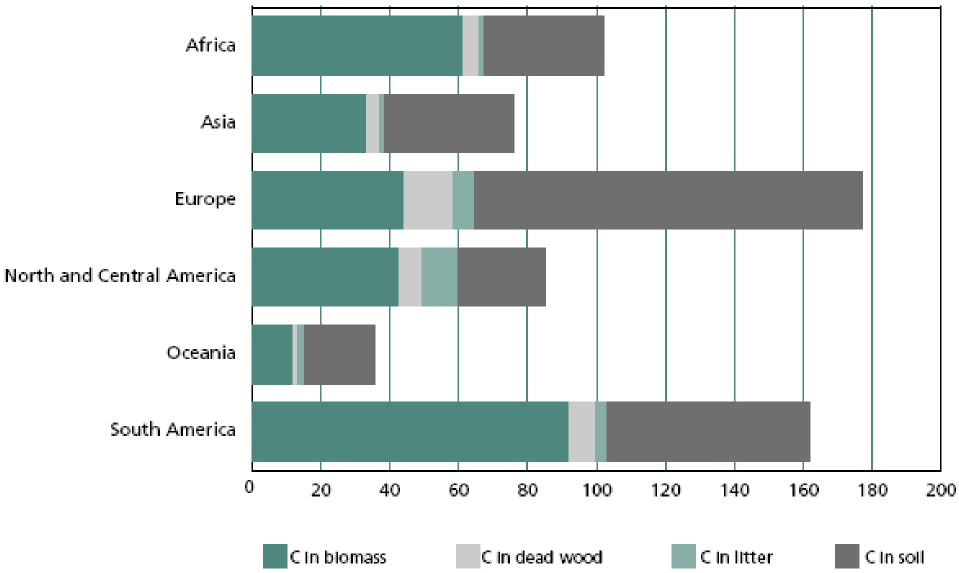

Figure 3: Total carbon stock (C) in forests by region 2005 (Gt), Source: FAO (2005)

There is a general trend of decreasing carbon stocks in forest biomass world wide, however developments are different from region to region. The decrease in overall biomass carbon stocks recorded from 1990 to 2005 was mainly driven by South and Southeast Asia (33% decrease), Western and Central Africa (7%) and South America (6%) while carbon in biomass remained approximately constant in Oceania and increased in Europe and in North and Central America in the same time span (FAO 2005).

Biomass supply

With timber and other woody biomass forests provide an important energy source. Although fossil fuels dominate world energy use, traditional use of biomass as fuel is still significant, some 10–15% of the world energy use (CIFOR, 2003).

Without wood products, we would be using other, more GHG intensive materials not only for energy production like mineral oil but also for building and construction, since wood can substantially replace steel, concrete, glass, aluminium, etc. (Schlamadinger, 2007). Since the Kyoto Agreement obliges to reduce emissions of greenhouse gases there is an even stronger interest in world forest resources to become a more strategic renewable resource for energy products thereby replacing fossil fuels (Hillring, 2006).

Consequently, industrial use of wood fuel is increasing. In the energy sector, the main industrial wood use is for heat production and electricity production both in stand-alone plants and in Combined Heat and Power plants (CHP plants). Beside timber from round wood which is often too expensive to use for the generation of energy, other products from forests that can be used are logging residues, wood from pre-commercial thinning and (to a certain extent) deadwood (Schlamadinger, 2007). For an efficient energy use these products can be converted in wood chips, pellets, briquettes, black liquor etc.

To an increasing extent wood is also considered to be an important resource for liquid biofuels. While recent biofuels such as biodiesel and bioethanol are almost exclusively based on agriculture feedstocks, some of the so called second generation biofuels (e.g. biomass to liquid) will require wood as the main resource among others for an economically feasible application.

It is often argued by politicians and advocates of biofuels that current sustainability problems in production of biofuels can be limited with the forthcoming of the second generation. In the past decade, the industrial use of wood for energy production has increased significantly; further extension of international trade in timber products especially with exports from countries with big forest resources to industrialised countries with ambitious targets in replacing fossil fuels by renewable energies can therefore be expected (Hillring, 2006).

The degree to which sustainable forest management is applied will be crucial on how big gains in GHG savings are in comparison to other products.

Microclimate regulation

Forest cover basically influences all variables of regional climate: solar radiation, air and soil temperature, rainfall, air humidity and wind (Aussenac, 1999). In general, forest cover buffers the daily and seasonal temperature differences compared to open ground and notably the clearfelling areas, thereby alleviating microclimatic extremes. The shelter characteristics of forests protect from frost in winter and have a cooling effect in summer. Forest canopy also influences and reduces wind speed depending on size and spatial distribution of the biomass within the forest. In general, forest stands have higher evapo-transpiration rates than other types of vegetation. The water which is given into the air has cooling effects because of increased radiation reflection made up by vapour and clouds and causes regional precipitation.

Forest cover is in most cases darker than other forms of vegetation or land surfaces. On a macro scale level this results in a comparably higher absorption of solar radiation compared to other brighter surfaces such as agricultural land where reflection rates are higher. From a climate change perspective this is a countervailing effect since the absorption of radiation rather enhances warming.

3.2.2 The role of forests in small and large scale water cycles

Forests modulate water flows in various ways that can differ significantly among regional conditions and forest types. Forest floors, with their leaf litter and porous soils, easily accommodate intense rainfall. Water infiltrates the ground until soils are saturated.

The "sponge effect" of forest ecosystems makes overland runoffs smaller and runoff timing longer compared to other land surfaces. Consequently, forests strongly contribute to the flood prevention when rainfalls are heavy. The filtration functions of forests are important also for water quality. Water running off from forested hills is far cleaner due to slower infiltration processes than fast run-offs from pastures or agricultural land.

An off-site effect of the water storage function can be decreases in stream flows with negative impacts on people living on the riverside and depending on continuous water supply. However, in the long run, afforestation mostly turns out to be beneficial for global hydrological cycle. Positive effects (reduced runoff and erosion, improved microclimate and increased control over nutrient fluxes) usually outweigh the off-site effects (lower base flow) since in situ vapour flows may also enhance regional precipitation with benefits for downstream users (Gedney et al., 2006; Matthews 2006 cited in Zomer 2006).

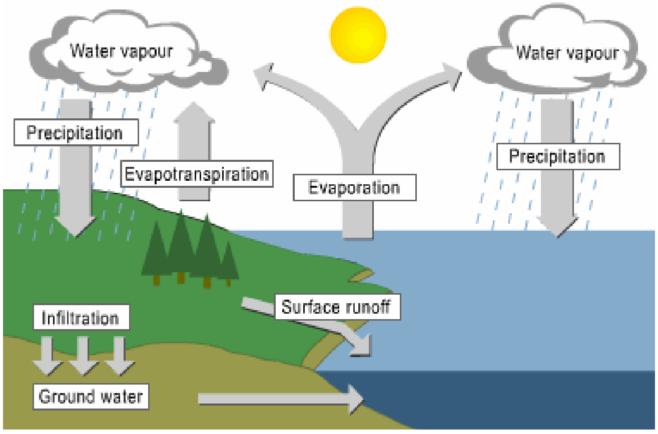

Figure 4: The Water Cycle[38]

Somewhat contradictory to the ecosystem service of water storage forest provide, trees also pump huge amounts of water into the air through evapo-transpiration. A tree releases 8-10 times more moisture into the atmosphere than the equivalent area of the ocean (Global Canopy Programme 2007). The difference of atmospheric water to water that has run off in stream flows is that it leads to precipitation - in many cases within reasonable geographic distances. This is especially important for land use in dry areas. In addition, water acts as air conditioner, cooling the atmosphere with vapour evolving to clouds reducing solar radiation.

The pressure created by evapo-transpiration causes additional water drawings from surrounding areas. For example, new research has shown that coastal tropical forests act as a 'biotic-pump' drawing water from the sea to any distance inland (Global Canopy Programme 2007).

In practice, many economic activities and human needs are dependant on such ecological processes. The Amazonian forest, for instance, stores 3 trillion tons of water (Global Canopy Programme 2007). 70% of Brazil's electricity is sourced by hydropower, also dependent on Amazonia's rain.

3.2.3 Forests, biodiversity and livelihoods

Forests play a crucial role in the lives of many poor people. Almost 70 million people – many indigenous – live in remote areas of closed tropical forests (Chomitz et al., 2007). Most are dependent on forests and their services are native forest dwellers who have a deeply rooted tradition in using the forest for their livelihoods by extracting a wide range of commodities such as food, fuel, fodder, wood, and medicine. Another 735 million rural people live in or near tropical forests and savannas, relying on them for much of their fuel, food, and income – or chopping them down for crops and pasture. While economic benefits from wood extraction for timber or charcoal production can be easily measured, the value of 'subsistence services' such as the firewood, vines or fruits collected for households can only be estimated on regional or local level.

[38] Source: Natural Resources Canada (http://ecosys.cfl.scf.rncan.gc.ca/dynamique-dynamic/cycle-eng.asp)

Biodiversity benefits people through more than just its contribution to material welfare and livelihoods. Biodiversity is not an ecosystem service itself. However, it is in many cases the underlying prerequisite for ecosystem processes providing regulating, cultural and supporting services (Kettunen and ten Brink, 2006). Hence, biodiversity contributes to important human needs such as security, resiliency, social relations, health, and freedom of choices and actions (MEA, 2005b). Forests, especially tropical rainforests, contain the highest biological diversity compared to other biomes in the world (MEA, 2005) (see also chapter 3.5.1).

3.2.4 Forests and climate change adaptation

All the functions described in the previous chapters show the crucial role forests have for stable climatic conditions. Intact forest ecosystems with their buffering functions (e.g. cooling effects, water storage and wind shield) can significantly contribute to adapt to biophysical changes induced by climatic change such as floods, droughts and temperature increase. Hence, synergies can be generated between forest management and adaptation strategies to climate change (Boyed et al., 2007). However, the linkages between climate change, forest ecosystems and the performance of the forest sector are currently not well understood. This is especially true for tropical forests (Robledo, 2004). A broad view on the different demands on forests is needed to optimise the forest management along these various factors.

3.3 Overview: Global Deforestation and Forest Degradation

Deforestation has to be distinguished from forest degradation although definition is not entirely clear. Deforestation is defined in the IPCC and UNFCCC documentation as “permanent removal” of forests and the conversion to other land uses (such as agricultural land) while degradation describes activities that lead to a significant reduction in either tree density or proportion of forest cover (from closed forests to open or fragmented forests) thereby decreasing its quality.

However, for better understanding and political acceptance scientists urge for a more distinguishing terminology. Among the most controversial issues is the differentiation of temporal wood extraction and permanent removal, the scale of forest clearance and the question whether canopy cover or biomass content should be used as the calculative measure for alterations in forests (Skutsch et al., 2007).

The detection of global deforestation and forest degradation is generally restrained by missing data from many regions in the world as well as by difficulties in measuring forest damages. Consequently, scientists come to different results when estimating global rates of deforestation and forest degradation. Achard et al. (2002) used satellite imagery to picture change in global humid tropical forest area for the period from 1990 to 1997. Results showed that 5.8 ±1.4 million hectares of humid tropical forest were lost each year, with a further 2.3 ± 0.7 million hectares of forest visibly degraded.

FAO estimates based on country reports are higher. For a similar period (1990-2000) the total net change in forest area accounts for -8.9 million hectares per year – equivalent to a loss of 0.22% of the remaining forest area each year during this period. For the period of 2000-2005 the total net change in forest area in the period is estimated at -7.3 million hectares per year, which is about the size of Panama or Sierra Leone. This number is equivalent to a loss of 200 km^2 of forest per day. These numbers show that overall deforestation rates have slightly decreased in the recent years.

As shown in Table 4 deforestation patterns differ greatly between world regions. South America suffered the largest net loss of forests from 2000 to 2005 followed by Africa. While there are signs that the net loss in Africa is decreasing, it seems to be increasing in South America – primarily due to a reported increase in the net loss of forests in Brazil. Serious forest declination can also be observed in South East Asia. Other regions, especially Europe and East Asia, record an increase in forest cover. It can be concluded that most deforestation happens in tropical areas while cover of temperate forests is rather on the rise.

Table 4: Annual changes in forest area by subregion 1990–2005, Source: FAO (2005)

Region/subregion	1990–2000		2000–2005	
	1 000 ha	%	1 000 ha	%
Eastern and Southern Africa	-1 731	-0.71	-1 702	-0.74
Northern Africa	-1 013	-0.72	-982	-0.73
Western and Central Africa	-1 631	-0.56	-1 356	-0.48
Total Africa	**-4 375**	**-0.64**	**-4 040**	**-0.62**
East Asia	1 751	0.81	3 840	1.65
South and Southeast Asia	-2 578	-0.83	-2 851	-0.98
Western and Central Asia	34	0.08	14	0.03
Total Asia	**-792**	**-0.14**	**1 003**	**0.18**
Total Europe	**877**	**0.09**	**661**	**0.07**
Caribbean	36	0.65	54	0.92
Central America	-380	-1.47	-285	-1.23
North America	17	n.s.	-101	-0.01
Total North and Central America	**-328**	**-0.05**	**-333**	**-0.05**
Total Oceania	**-448**	**-0.21**	**-356**	**-0.17**
Total South America	**-3 802**	**-0.44**	**-4 251**	**-0.50**
World	**-8 868**	**-0.22**	**-7 317**	**-0.18**

Note: percentages represent the proportion of remaining forest area lost or gained each year during the respective period.
n.s. = not significant

Recent technological developments in remote sensing have created the possibility to monitor deforestation and even forest degradation with high spatial accuracy. Various methods are available and appropriate to analyze satellite data for measuring changes in forest cover. These methods range from visual photo-interpretation to sophisticated digital analysis, and from wall-to-wall mapping to hot-spot analysis and statistical sampling (De Fries et al., 2007).

Hence, for the first time, accurate monitoring has also become possible for governments outside the forest nation. Equally, national and international NGOs can use the material in order to gather support for their cause and to point out precise spots where public control is insufficient (Chomitz et al., 2007). Brazil and India have started to make use of satellite images for fire monitoring and reporting on deforestation, and also disclose the information to the public via internet sites.[39]

[39] See for instance the DETER project run by the Brazilian National Institute of Space Research (INPE): http://www.inpe.br/ingles/institutional/mission.php

3.4 Causes of Deforestation and Forest Degradation

3.4.1 General background

More recent perspectives on the causes of deforestation were often dominated by single factor causation explanations and theories. Shifting cultivation and population growth often function as representative mechanisms that stood for the explanation of a widely misunderstood topic. However, many local or regional studies revealed a wide range of significant factors that drive deforestation and forest degradation.

Meanwhile, it is mostly accepted that causes of deforestation cannot be explained by general theories but have to be part of in-depth explorations of a wide range of economic, political and social issues. Causes and drivers of deforestation are very case-specific (Dutschke and Wolf, 2007) with some issues only relevant under specific socio-economic and political circumstances. Since deforestation and forest degradation are often side effects of non-forest policies, there is a big overlap to other policy fields that have to be taken into account (Krug and Köhl, 2007).

A possible approach to understand the complexity of the problem is to differentiate between general processes on a global level, underlying causes such as poverty and land use policy and drivers that directly (i.e. physically by wood extraction or forest burning) lead to impacts on forest ecosystems such as extension of agricultural land and illegal logging (see Figure 2). These different levels are linked to each other with either boosting or hampering effects on forest degradation. Beside the general processes three or four underlying causes (such as urbanisation, market growth and policies boosting infrastructure development) are usually driving one to three proximate causes (such as infrastructure extension and wood extraction) (Geist and Lambin, 2002).

There are actually three main processes that can be identified on the global level that are responsible for general increasing pressure on forest ecosystems followed by land use change and deforestation (Achard et al., 2006). These processes are not easy to encounter since origins are part of general developments linked to globalisation and economic growth.

- **Shift of agrarian activities** from industrialized countries to developing countries with lower manpower costs, less constringent legal environment constraints and less legal local people rights on available forest areas.
- **Unsustainable practices** cause the decrease of fertility of existing agricultural land (leading to a shift of agrarian activities on forest lands) and the overexploitation of forest resources.
- **Increase of demand for agrarian commodities** due to increase of human population and its per capita needs for food and at the same time steadily increasing demand for biomass as a renewable energy source as well as the expected increase in pulp and paper consumption world wide.

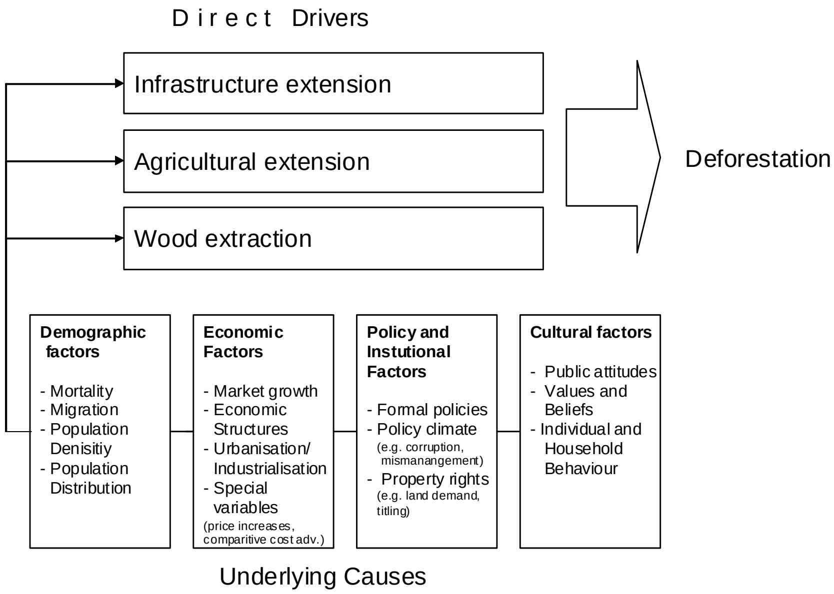

Figure 5: Causes of deforestation and forest degradation (Source: Geist and Lambin 2002)

Underlying causes such as political regulations, structure of population living in forestry areas and market drivers can seem unrelated to the deforestation problem and therefore left out of attention. However, a more detailed analysis reveals that these causes might turn out to be a major driver for certain cases of deforestation. Geist and Lambin (2002) compared 152 sub-national case studies from all over the world in regard to their major factors for deforestation. As the most important factors they identified economic and institutional ones that are further described in the following. It has to be noted that poverty is a major cross cutting issue that additionally enforces underlying causes of deforestation. Due to its complexity, an extended analyses on poverty as such cannot provided in this study. However, a few aspects are stressed in the following chapters.

3.4.2 Economic factors

Economic factors comprise all market related issues mainly concerning demand and cost parameters. Among the most important economic factors driving deforestation, Geist and Lambin (2002) identified the following:

- Growth of timber markets driven by increasing national and international demand for wood.
- Market failures (lack of integration of externalities).
- Differences in costs for land, tenure, labour or fuel often leading to enterprises pushing into areas and regions of developing countries where costs are low or can be limited.
- Requirements of developing countries to generate foreign exchange earnings for national economic development.

Under simple market conditions maintaining forests and generating returns from sustainable timber production always competes with predatory extraction, followed by agricultural conversion. Without additional economic incentives, forest owners or future forest claimants balancing profit expectations will often opt for land clearings unless forests contain precious woods, many saleable trees, fast-growing trees, or if soils are unsuited to agriculture (Chomitz et al., 2007). In many cases even low-return pasture or staple crops offer higher returns to landholders than timber production from old-growth rainforests with diverse, slow-growing species. Yet, this decision might be different if preferences for long term benefits (expressed by a low discount rate) instead of short term profit expectations dominate and if demand for forest environmental services was included.

High profits can be expected if soils are rich enough for profitable agricultural use and if labour costs can be limited. On the other hand incentives for converting forest land into agricultural land are limited on marginal land, lands far from markets or where agricultural technologies are unavailable (Chomitz et al., 2007).

It has to be noted that expenses for land clearings are high especially in tropical areas where infrastructure is poor. Large scale deforestation is mostly made by enterprises with sufficient capital while smallholders can rarely afford deforestation because of financial and technological constraints. However it was often observed that poverty driven deforestation does not take place until companies with interests in deforesting land make investments in infrastructure. Farmers who are economically marginalised by large scale production or even lost their resource entitlements and property rights are forced to illegally intrude in intact forests using previously installed infrastructure to do so (Rudel and Roper, 1997). In some areas this leads to slash and burn activities with serious impacts on forest ecosystems.

As already mentioned above, land conversion is boosted by higher demand for agricultural products for bioenergy, so called energy crops. Driven by ambitious targets for replacing fossil fuels by liquid biofuels, industrialised countries such as those of the European Union and the US cause immense additional pressure on land in developing countries playing the role of cheap suppliers of biomass resources in the future. The increase in prices for agricultural products due to high demand for biomass makes small and large scale land conversion even more profitable. Private investments in land conversions are driven by national promoting policies for biomass production and bioenergy. Countries like Brazil, Indonesia, Malaysia but also many others in Latin America, Africa and Asia have launched biomass programmes pushing to extensions of agricultural land at the expense of forests. Using current figures of fuel consumption and considering a 10% substitution scenario[40] would result in an additional request for available land of approximately 5.6 million ha/year during the 2010s (3.2 million ha/year for sugar cane and 2.5 million ha/year for oil palm) (Archard et al., 2006).

[40] 10% biofuels target as agreed by EU Ministers in spring 2007.

These relations show that the over-use of forest resources often follows economic rationality with particular interest in short term profits or just in survival, which is facilitated by a lack of governance and by legal uncertainty (Krug and Köhl, 2007).

3.4.3 Institutional factors

Geist and Lambin identified three major issues constituting the institutional driving factors for deforestation and forest degradation (see also Figure 3):

- Incentives given by national policies.
- Low level of governance and law enforcement.
- Insecure property rights.

National governments policies can have direct or indirect incentives for deforestation or an intensive forest use leading to forest degradation. Some land tenure policies stipulate that rights to land are only given when land is cleared (Montagnini and Jordan, 2005). Others stimulate deforestation through investment incentives, credit concessions and tax provisions or agricultural pricing policies, and instruments on leasing and selling forest exploitation rights. The establishment of such instruments is often driven by increasing domestic or international demand for products that require land for its cultivation. In Brazil, for instance, a whole set of supporting policies were created to boost the production of sugarcane as international demand for bioethanol is expected to rise significantly. Subsidies and tax alleviation shall also attract companies to invest in the region thereby boosting economic development and employment.

In many tropical countries **low levels of governance** render legislation ineffective: lack of capacity to administer existing laws or to co-ordinate efforts between government agencies inside and outside the forestry sector contribute to failure of implementation (World Bank, 2006).[41] Prosecution or penalty measures that are high enough to deter profitable logging operations are often missing in national legislation. Corruption aggravates this problem when already weak legislative frameworks are further undermined by bribing officials to ignore intrusions in forest ecosystem. There has thus been a dramatic increase of foreign investments in tropical logging by companies which take advantage of this weak legislation (Laurance, 2000).

In some areas, **property rights issues** are of high relevance leading to ambiguous impacts on forest cover (Geist and Lambin, 2007). These issues comprise insecure ownership, quasi-open access conditions, maladjusted customary rights as well as the legalisation of land titles.

In the Brazilian Amazon, for instance around one third of the forests – the *terras devolutas* – have an uncertain ownership status, leaving them legally unprotected (Dutschke and Wolf, 2007). Even if traditional land rights exist, they are often not codified, which leaves local populations defenceless against a change in the legal status. Once the land becomes open access land, incentives for capturing wood resources are high due to uncertain legal status.

[41] For a case study of Indonesia which suffers from the combination of a high density of valuable timber and particularly low forest governance see: World Bank/WWF (2005), Illegal Logging and Law Enforcement in Indonesia: Draft Summary Results From the WWF/World Bank Alliance Assessment of Illegal Logging and Law Enforcement (2002–2004). World Bank: 2005.

Agricultural land has stronger ownership status than forests, the former being regarded as land under cultivation, thereby provoking the so-called "land race": land claimers compete for the area by clearing as much forest as they can (Dutschke and Wolf, 2007).

3.5 Impacts of deforestation

3.5.1 Impacts of deforestation on biodiversity

There is a clear relationship between deforestation and loss of forest biological diversity. On large scales, evidence exists that the forest biodiversity (e.g. genetic diversity and the diversity of forest species and ecosystem) is related to total forest area (CBD, 2002). In all forest biomes, far fewer intact larger blocks of primary forests now occur (e.g. compared to 100 years ago) with the existing small forest fragments retaining only a small portion of the normal species complement. In addition to the decline in total area, the remaining forest systems also tend to be degraded or replaced by secondary vegetation further affecting the level of forest biodiversity. Thus, it is clear that forest biological diversity is rapidly declining due to deforestation and degradation of forest ecosystems, especially in the tropics.

It has been noted that the majority of species (both animal and plant species) facing extinction are those from forest and woodland ecosystems (WCMC, 1992). The current extinction rate is a historically high level (1000 to 10000 times higher than the rate at which species evolve) and deforestation and forest degradation have been identified among the main causes for the negative trend. According to the existing information, the number of threatened and endangered forest species seems to correlate with the size and quality of forest habitats, temporal and spatial continuity in the forest landscape, and with the history of forest use (CBD, 2002). For example, certain forest species are climax forest species, thus they depend, for instance, on standing dead trees or on dead wood lying on the forest floor. Both of these specific habitats tend to be absent in highly managed forests.

In the absence of a unified global habitat classification system it is difficult to provide comprehensive estimates of how many forest species are threatened. However, some specific data are available for individual tree species and some forest habitat types. For example, it has been estimated that 900 threatened bird species rely on tropical rainforests, with 42% of these occurring almost exclusively in lowland rainforest and 35% occurring in mountain rainforest. Among mammals, 33% of those threatened occur in lowland rainforest and 22% in mountain forest[42] (Hilton-Taylor, 2000). The total number of globally threatened tree species has been reported to be 8753, equating to about 9% of the world's estimated 100 000 tree species (CBD, 2002). Similarly, the list of priority species established by the FAO Panel of Experts on Forest Gene Resources (FAO, 2000) also suggests that around 9% (48 species out of 524 tree species recorded) of the world's most important trees[43] are threatened, at species or population level. The loss of any tree genus or species will be accompanied by the loss of a variable and unknown number of obligate-associated species (including parasites, predators, pollinators and microsymbionts) and understory plant and animal species. In the tropics, the number of such associated species may be conservatively estimated to be of the order of 10 to 100 per tree species.

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[42] Note: it is not yet clear what proportion of these mammals are totally dependent on forests for their survival

[43] Species presenting highest actual or potential value, at species or population level

As regards fragmentation, forest fragmentation effects have been noted to result in numerous local extinctions and provide an important threat to species. There is good evidence that, at least in certain parts of the world, extinctions of forest species take place if the habitat becomes fragmented and mixed with non-forest areas (e.g. Andren 1994). Such extinctions can occur even if the forest in the surviving fragments remains undisturbed. This phenomenon has been demonstrated in particular in the Americas (e.g. Lovejoy et al., 1986), however evidence from other parts of the world also exists. For example, many bird species have been affected in the heavily cleared woodland communities of eastern Australia and are now declining at an alarming rate, with 20% of Australian bird species now considered threatened (Garnett, 1993; IUCN, 2000).

As regards the genetic diversity, it has also become evident that genetic diversity has been severely eroded due to forest decline. For example, in all areas where deforestation has been extensive, it is likely that genetically distinct, unique populations of plant and animal species have disappeared (CBD, 2002).

Changes in forest cover can also affect biodiversity in the neighbouring ecosystems. For example, deforestation can change and/or cause decline of biodiversity in connected river and stream ecosystems. For example, forest leaf litter plays an important role in stream systems' food webs, thus contributing to the maintenance of diversity and functioning of these ecosystems (e.g. in Giller and O'Halloran, 2004; Reynolds, 2004). Woody debris also provides shelter to a number of aquatic species, thus affecting their distribution (e.g. salmonids). In addition, changes in water quality resulting from deforestation (see Section 1.1.2 below) can have an impact on aquatic community composition and lead to decrease in biodiversity. For example, there is evidence of salmonid decline due to deforestation related changes in water quality.

The loss of biodiversity, including the decline and loss of species and their genetic diversity and/or the loss and degradation of forest ecosystems, can further on lead to the loss of forest related ecosystem services (see Section 1.2). This can occur due to the overexploitation and decline in certain valuable forest species (e.g. provisioning of food and timber). Alternatively, the loss of species or decline in species abundance can alter the functioning of ecosystems, thus negatively affecting the ecosystems' ability to provide several regulating, cultural and supporting services.

In addition, loss of biodiversity can potentially affect forest ecosystem resilience, i.e. the capacity to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks. This means that the negative impacts of biodiversity loss on ecosystem functioning and services might come apparent only in due course, e.g. with increased effects of climate change.

3.5.2 Impacts of deforestation on ecosystem services

Climate regulation

Forests play an important role in regulating the global carbon balance, thus affecting climate change. In short, photosynthesis by forest vegetation removes carbon from the atmosphere by incorporating it into biomass, consequently making forests function as a **carbon sink**. It has been estimated that forests sequester the largest fraction of terrestrial ecosystem carbon stocks, recently estimated at 1,640 PgC (Sabine et al., 2004), equivalent to about 220% of atmospheric carbon.

Deforestation results in a decline in overall carbon storage function of forests. It also increases atmospheric carbon levels by releasing carbon stored in biomass and as soil carbon, i.e. carbon in living and decaying matter locked in forest soils. Consequently, deforestation and land conversion have been significant sources of greenhouse-gas emissions for decades. The release of carbon due to deforestation can take place both rapidly, i.e. when burning forest biomass, and slowly through the loss and degradation of biomass based products over time. The current assessments indicate that the deforestation and degradation rates in tropical and subtropical regions (e.g. Hassan et al., 2005 are leading to about one-quarter of anthropogenic CO^2 emissions (e.g. Houghton, 2003, 2005).

In addition, deforestation may also indirectly affect carbon regulation service in nearby forested areas. This is because deforestation may change the local climate regimes and increase the overall risk for forest fire in the region (see Section 1.2.3 below).

It is also to be noted that changed in precipitation and temperature levels due to climate change might have feedback effects on forests carbon capture ability. For example, changes in precipitation influence the litter input to soil, thus the level of carbon captured in forest soil. Studies suggest that climate change impacts on C storage differ between different regions (Falloon et al, 2007). In the context, the recent study published in 2008 indicates that northern terrestrial ecosystems may currently lose carbon dioxide in response to autumn warming offsetting 90% of the increased carbon dioxide uptake during spring (Piao et al., 2008). Consequently, if future autumn warming occurs at a faster rate than in spring, the ability of northern ecosystems to sequester carbon may be diminished earlier than previously suggested.

In addition to the carbon balance, it has been observed that deforestation also effects the ability of forests to **regulate local and regional climate** (e.g. in Amazonia) by decreasing evapotranspiration, i.e. the sum of evaporation and plant transpiration from the earth's land surface to atmosphere, resulting in warming of soil surface. This inhibits convection (i.e. heat transport) and causes decrease in the formation of cloud cover and precipitation (e.g. Foley et al 2007). There are also some evidence on potential global effects, for example according certain studies large scale deforestation in Amazonia could potentially effect North Atlantic and European storm tracks causing substantial cooling in southern Europe and warming in some parts of Asia in winter.

Water regulation and purification

Forests play an important role in regulating water quantity and quality. For example, it has been estimated that over 75% of globally usable freshwater supplies come from forested catchments (Shvidenko et al., 2005). As regards water quantity, deforestation can lead to changes in evapotranspiration (see above) and increased surface runoff (i.e. flow of water over the land surface). This in turn can affect the circulation and availability of water within the ecosystem. For example, in Amazonia deforestation has been observed to cause decrease in **evapotranspiration** and precipitation, both at local and regional scale (Foley et al. 2007). In several cases (e.g. in Amazonia, Indonesia and the US) local increases in **runoff discharge** and stream flow due to deforestation have been observed (e.g. Suna et al., 2005, Foley et al., 2007, Pattanayak and Wendland 2007). The regional effects of deforestation on runoff still remain unclear, however some evidence on increased runoff due to loss of forest cover exists also at river basin level (e.g. Tocatins basin in Amazonia).

Local decrease in baseflow cause by deforestation (i.e. the portion of streamflow that comes from groundwater) has also been observed (Himalaya) (Bandit et al., 2007).

As regards the impacts of deforestation on **flooding**, it has been noted that decrease in forest cover may increase the scale of flooding on at local scale. Consequently, there is evidence that at local scale forests and forest soils are capable of reducing runoff, generally as the result of enhanced infiltration and storage capacities. As regards the forest soils, the regulating effect depends also on soil depth, structure and degree of previous saturation. However, it seems that forests have only a limited influence on major downstream flooding at the basin level (e.g. CIFOR, 2005). Additionally, during a major rainfall event (like those that result in massive flooding), especially after prolonged periods of preceding rainfall, the forest soil becomes saturated and water no longer filters into he soil but instead runs off along the soil surface.

Regarding **water quality**, deforestation can affect the quality of water in streams at local level (e.g. Giller and O'Halloran, 2004; Reynolds, 2004; Langan and Hirst, 2004). Deforestation and forest harvesting have been observed to increase nitrate, sea salt and suspended solid levels in stream systems (e.g. in Wales and Ireland). It has also been noted that forests have the capacity to capture pollutants with atmospheric origin, thus deforestation might increase the level of these pollutants in stream water (Scotland). Additionally, some decline in ground water quality due to deforestation has been detected (e.g. in Wales).

In general, the effects of deforestation on water quantity and quality depend on the scale and heterogeneity of the deforestation. Also the climate features and topography play a role in final outcomes of deforestation. For example, the studies from US indicate that hilly upland systems have a relative high hydrological response to changes in forest cover and are slower to recover. Thus, even though clear evidence on negative effects of deforestation on water quality and quantity exists one should be cautious in interpreting the results at regional and global level.

Other forest related ecosystem services

As regards a number of other forest related services, deforestation and changes in forest species composition and structure can also increase the risk of **forests fires**. For example, natural ecosystems in areas with a history of forest fires are generally characterised by fire resistant species. However, changing the species composition and ecosystem structure, e.g. by planting monocultures and/or increasing biomass of grass vegetation, may increase the frequency and intensify of forest fires. Additionally, climate change is known to further alter the likelihood of increased wildfire sizes and frequencies.

Deforestation is also known to degrade **soil quality**, e.g. soil organic matter and nitrogen levels. It has been acknowledged that forests, in particular, the undergrowth and forest litter, can control erosion and sediment processes. In addition, tree roots play an important role in **slope stability** and can indeed give the soil a certain amount of mechanical support. However, this might be limited to shallow (<1m) mass movements (Bruijnzeel 1990, 2002; O'Loughlin, 1974).

Deforestation can also have a negative effect on ecosystems' capacity to **control diseases**. For example, deforestation is known to change the distribution patterns of malaria vectors (mosquitoes), thus contributing to malaria upsurge in tropical areas (E.g. Tuno et al., 2005). Additionally, overall changes in water quantity, availability and quality cause by deforestation, e.g. in the case of increased local flooding, might increase risk of epidemics. For example, evidence exists on a link between a decrease in water quantity due to deforestation leading to increase in diarrhoeal diseases (Pattanayak and Wendland 2007).

3.5.3 Socio-economic impacts of deforestation

Forest ecosystems services provide several socio-economic benefits to the society. Consequently, the loss of these services (as outlined above) due to changes in forest cover and structure (e.g. deforestation) can result in significant socio-economic, including monetary, losses.

For example, the expansion of fire prone plantation forests has significantly contributed to the increase of wildfires in Portugal (see Kettunen et al., 2006). In the last 25 years (1980-2004), fires have burned over around 2.7 million hectares of forest land. Considering only the direct losses associated with primary production, the estimated costs have been about €300 million per year. The total investments in fire fighting and prevention amounted to €479 million in this five-year period (€17.8/hectare/year). In 2001 alone, the damage caused by forest fires amounted to about €137 million (e.g. costs of fire prevention, fire fighting and reforestation, and losses of forest products).

Additionally, it has been estimated that the provision of good water quality by natural forests in Bavaria is about €500 million per year (German Federal Office for Conservation 2005). Similarly, the total value of the woodland ecosystem services in Great Britain is estimated to be €42,924 million (Willis et al., 2003). These figures provide an estimate for the likely economic costs resulting from the loss of these forest ecosystems due to deforestation.

Naturally, the provisioning of timber constitutes a forest related service with considerable global economic value. Sustainable management of timber production and logging is, however, of crucial importance in order to maintain ecosystems' capacity to provide the range of other services, including water and climate regulation. Short term economic benefits gained through clear cutting and deforestation are therefore not considered sustainable on a long term basis. Additionally, profits arising from such activities often benefit only few stakeholders whereas the costs are shouldered by much broader group. In particular, in the context of developing countries poor populations are often very dependent on the availability of the full range of forest ecosystems services for their wellbeing and survival (e.g. supply of pure water and availability of non-timber forest products).

3.6 Policy approaches and Economic Perspectives on combating deforestation in the future

The causes of deforestation are multiple, complex and region-specific. In order to be effective in the long term, policy approaches to reduce the loss of forests have to adequately address these interrelated drivers of deforestation. The response strategies discussed in the following sections include regulatory instruments, the allocation and protection of property rights, and economic incentives all of which can originate on different policy levels – from local initiatives to policy on the international level.

When judging their effectiveness, it is crucial to recognise that these policy measures will have to be implemented and enforced on the national and sub-national level. This is also true for the option which has recently attracted most attention, namely the proposal to create financial compensation for reduced emissions from deforestation and degradation (REDD) within the UNFCCC framework.

3.6.1 Regulatory Instruments

Legislation is a traditional policy instrument used to combat deforestation, mainly by establishing rules which prohibit illegal logging, regulate land use on privately-owned land and state property or install protection zones. For these rules to be effective in curbing deforestation, proper enforcement remains the most important challenge. As described above, low levels of governance render legislation ineffective in many tropical countries – forested nations as well as the international community are therefore seeking new tools to effectively implement forest laws and regulations.

Protection of property rights and land-use planning

The majority of tropical forests in Asia, Africa and Latin America are in nominal state ownership. Two common management options for public forests exist: the **establishment of protected areas** or a **regime of regulated concessions**. Brazil and Paraguay, for instance, prescribe that a proportion of privately-owned land must remain forested. Within protected zones land use rights for private owners can be even further restricted, allowing only a limited number of commercial activities such as ecotourism.

The effectiveness of forest protection hinges in both cases on the ability of governments to enforce the rules on land use. Unfortunately, quantitative evidence evaluating managing practices is very sparse overall. For instance, although protected areas now cover about a seventh of global forests, evidence on their effectiveness in halting forest conversion remains patchy. The existing case studies suggest lower conversion rates within parks which could be an argument for extending protection zones. However, the social and economic costs for livelihoods of forest peoples have to be factored into the decision (Chomitz et al., 2007).

As an alternative, central governments, notably in Latin America, have started to devolve **forest management to local communities**, including indigenous groups, in an attempt to harness local knowledge and practices for sustainable forest management. Again, the evidence on the success of community-based or participatory forest management (PFM) is sparse, but a number of common challenges have nonetheless been identified. Case studies suggest that devolving responsibility needs to be accompanied by capacity-building and resources for the local community so as to allow them to effectively self-organise, to monitor and protect the community resource as well as to equitably allocate benefits. Indeed, local level decision-making is not necessarily less susceptible to corruption, mismanagement and capture of decision processes by elites than centralised forest administrations. Long-term prospective and accountability of local administrators increase the chances of success (Chomitz et al., 2007).

Recently, **land-use planning** has been promoted as a tool to rationalise these tenure systems and optimise effectiveness of land use for both agriculture and biodiversity protection. Based on crop modelling, soil data and species distribution data, planning agencies define different land use zones – ranging from agricultural lands and forest concessions to biodiversity corridors and protected areas.

In this process, planners might need to curtail rights of existing owners or groups with traditional, but not formally acknowledged, tenure rights such as for instance indigenous peoples' hunting rights. Experience with zoning, mainly in Latin America, has shown that it can only be effective if relevant stakeholders participate in the planning process. Ideally, participation would lead to a situation where "maps [are adapted] to reality on the ground rather than vice versa" (Chomitz et al., 2007). The challenges of participatory zoning include:

- defining legitimate participants;
- avoiding capture by elites; and
- enforcement of zoning agreements.

Many drivers of deforestation result from economic forces and policy decisions outside the forest sector. As such, governments' most powerful instruments for influencing deforestation are probably development and economic policies, rather than in the decisions in forestry sector. As explained in chapter 4, infrastructure decisions are paramount in this regard. If zoning is to be successful, careful decision-making on where to build roads and where to leave forests without access routes has to be an integral part of the planning exercise. Likewise, land-use decisions outside intact forests can considerably influence the pressure in the frontier area. Intensification of agricultural practices outside the forest, for instance, can reduce the pressure to convert forests into agricultural land (Chomitz et al., 2007).

Illegal Logging

Laws forbidding illegal logging exist in virtually all countries, but enforcement is often ineffective. Recently, however, significant technology innovations have created a new set of instruments for control and enforcement (see chapter 3).

Given the difficulties of forest law enforcement in many tropical nations, governments in timber-importing countries are increasingly seeking ways to encourage a more effective regulatory regime in producer countries. In the EU, these efforts are summarised in the Action Plan for Forest Law Enforcement Governance and Trade (FLEGT). As a first vital step, the FLEGT process focuses on ensuring legality of timber, with the ultimate goal of encouraging sustainable management of forests.

The main elements of the Action Plan include:

- capacity building in timber-producing countries;
- bilateral voluntary partnership agreements (VPA) with timber-exporting countries;
- guidelines for procurement;
- a voluntary private sector initiative to increase good practice, e.g. to use certification;
- banks and other investors who finance forest operations are asked to ensure legality of operations; and
- encouragement of Member States to designate illegal logging as a crime for the purposes of the EC Directive on money laundering.

At the core of the FLEGT approach is the bilateral Voluntary Partnership Agreements (VPA) with timber-exporting nations. Once agreed, the VPAs will include commitments and action from both parties to halt trade in illegal timber, notably with a license scheme to verify the legality of timber. The agreements will also promote better enforcement of forest law (Regulation No. 2173/2005 EC).

The Commission is currently negotiating with Malaysia, Indonesia and Ghana, and a number of other countries have also expressed interest in VPAs (World Bank, 2006).

Due to stakeholder criticism regarding the effectiveness of the scheme, FLEGT is now subject to review. The public consultation process highlighted a number of concerns linked to:

- the limited geographical scope and the limited range of products covered;
- the circumvention and laundering risk when timber from third partners arrives as FLEGT-licensed timber in the EU or illegal FLEGT timber is imported from EU neighbouring countries into the EU with a false official origin; and
- the voluntary private sector certification schemes which many NGOs criticise as ineffective and in some cases substantially flawed, while private sector refers to the efficiency of the approach compared to legislative action (European Commission, 2007).

Several environmental NGOs, notably Greenpeace, propagate an import ban on illegal timber as an alternative to the voluntary FLEGT approach, arguing that a ban could establish a level playing field for legal traders and improve the image of timber. Besides concerns about the compatibility of such a ban with international trade law, opponents highlight that no internationally agreed definition of illegal logging exists. Furthermore, the requirement of a fraud-resistant traceability mechanism is feared to produce high implementation costs – for communities and other small-scale producers those costs risk being prohibitive. Most commentators therefore emphasised the need for combining legal instruments with intensive capacity-building in producer countries (European Commission, 2007).

The EU FLEGT scheme is one element in a broader set of national, regional and international FLEGT activities led by governments, intergovernmental organisations, NGOs and the private sector. Key initiatives include:

- Regional FLEGT ministerial conferences conducted in Asia, Africa and Europe/ North Africa;
- the Asia Forest Partnership which encourages sustainable forest management in the region;
- the International Tropical Timber Agreement lead by the International Tropical Timber Organisation (ITTO) which aims at strengthening enforcement capacity and addresses illegal logging and related trade in tropical timber;
- bilateral programmes such as the US "Initiative Against Illegal Logging"; and
- Government initiatives to promote responsible timber procurement, mainly in Europe and Japan (World Bank 2006).

The described gamut of initiatives shows how high the issue has risen on the international agenda. According to a World Bank assessment, on-the-ground impact of most programmes is, however, still limited since they have not resulted in reform of national enforcement systems (with the important exception of Indonesia and Russia) nor have multilateral enforcement mechanisms been created. Another challenge for the future is the incorporation of efforts to combat illegal forest activities into broader tools for the promotion of good governance and the combating of organised crime (World Bank, 2006). The EU's approach to harness anti-money laundering legislation and due diligence for foreign investment as instruments against illegal logging is a first step in this direction.

Innovative regulation and enforcement mechanisms have an important role to play when tackling the loss of tropical forests, but it will not be possible to use regulation alone in the face of overwhelming economic forces. In the long run, forests will only remain intact if the local communities which live near or in them can benefit from standing forests. In the following section, we will therefore turn to policy strategies which build on economic incentives.

3.6.2 Economic incentives

Economic incentives and alternative income sources to make standing forests profitable include:

- carbon finance;
- certification for sustainable timber harvesting;
- ecotourism;
- non-timber forest products; and
- Payments for Ecosystem Services schemes (PES).

In terms of potential funding for all forests, compensation for the carbon stored in forests (carbon finance) is by far the most important option. It will therefore be discussed in more detail in a separate section below.

Certification

Certification serves as a signal for consumers that the timber is harvested in a sustainable manner. It builds on consumers' willingness to pay a price premium which can be used to finance the conversion to less damaging harvest practices. There are at least eight different schemes with fundamentally different principles and accreditation standards. With the exception of the Forest Stewardship Council (FSC), most of these schemes have been developed by the forestry sector, and they are critiqued by the NGO-community for dependence on vested economic interests as well as for their lack transparency (FERN, 2004). By contrast, the FSC, which has been set up in 1993 by NGOs, forest companies, timber traders and other stakeholders, mostly enjoys the trust of the environmental community for its transparent and participatory decision-making process, its clearly-defined global principles and regional indicators, as well as for its chain-of-custody tracking system (WWF 2001). By the end of 2006, global FSC-certified forest area amounted to 84.3 million ha, representing a share of 0.6% of total forest area (FSC Homepage Germany).

The advantage of certification is its power to foster enforcement even in the absence of effective local institutions by rewarding good performers rather than penalising them. But it remains questionable if it can influence producer behaviour at a large scale since accreditation is costly and can only be profitable to the extent that a majority of consumers is willing to pay a substantial premium (Chomitz et al., 2007).

Ecotourism and non-timber forest products

With the aim of providing livelihood to forest dwellers without increasing pressure on forests, alternative sources of income have been explored. Ecotourism and the promotion of markets for non-timber forest products such as natural rubber, nuts or medicine are two of the main options.

Examples include the Brazilian state of Amazonas, where the government has introduced a subsidy for rubber tappers in 2003 together with a general tax exemption for non-forest products[44]or the efforts to promote ecotourism in Costa Rica.

The effectiveness of both conservation strategies is limited in scale – they rather represent niche opportunities. In the case of ecotourism this is mainly due to the fact that only a limited number of sites are suitable and attractive for tourists. Tropical forests are not necessarily the most interesting option, savannahs with their large mammals are often more attractive. Equally, income from non-timber forest products can not be scaled up to cover a large fraction of forest dwellers' needs since market access is often limited, as is the demand for the products (Chomitz et al., 2007).

Given the constraints of indirect approaches to increase the economic value of standing forests, several governments have turned to a system of direct payments for ecosystem services.

Payment for Ecosystem Services (PES) schemes

The idea behind environmental service payments schemes is to directly reward landholders for the environmental benefits they provide either to a certain group or to society as a whole when maintaining forests. PES schemes exist in several countries. The longest-running and best-known initiative is the PES scheme in Costa Rica. Introduced in 1996, the programme pays landowners for four kinds of environmental services associated with maintaining forest cover (Wertz-Kanounnikoff, 2006):

- mitigation of greenhouse gas effects;
- water protection;
- biodiversity protection; and
- scenic beauty.

More recently, Costa Rica has teamed up with Columbia and Nicaragua for the establishment of the Regional Integrated Silvopastoral Ecosystem Management Project which compensates landowners for the adoption of agroforesty practices on formerly treeless pastures. Similar schemes in Mexico and China focus mainly on hydrological services. In Mexico, landholders can receive up to US$27 a hectare per year to conserve cloud forest. The Chinese Sloping Land Programme tackles sedimentation in the Yangtze and the Yellow river by offering incentives to landowners who plant grass or trees on steep, erosion-prone farmland (Chomitz et al., 2007). Compensation for watershed protection services offer the advantage that beneficiaries are more easily identified – and thus securing funding is more straightforward – than for other ecosystem services with more diffused benefits (Pagiola et al., 2004).

Evidence on the effectiveness of PES schemes is mixed and commentators have also raised a number of equity concerns regarding the distribution of benefits, arguing that in the Costa Rican scheme participants are predominantly large-scale private owners with comparably higher income and education level than other forest residents (Sierra and Russman, 2006; Zbinden and Lee, 2005).

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[44] See homepage of the Amazonas State Government: www.sds.am.gov.br

Thus, the prerequisites of successful PES schemes include (Chomitz et al., 2007):

- appropriate and continuous financing;
- clear and equitable definition of eligibility; and
- effective monitoring of funds and compliance control.

3.6.3 Integrating REDD into UNFCCC

Probably the most diffuse benefit of forest protection results from the storing of carbon since the global population as a whole profits when greenhouse gas emissions from land use change are reduced or avoided. As emissions trading schemes develop in several industrialised countries and between the Parties to the Kyoto Protocol, intense discussion focuses once again on whether the willingness to pay for carbon storage can be harnessed to save tropical forests. The option had already been discussed in 2001, when the implementation rules of the Kyoto Protocol were negotiated. At the time, it was suggested to include avoided deforestation projects into the Clean Development Mechanism (CDM), a Kyoto Protocol mechanism which allows the industrialised Annex-1 countries to generate emission reduction through sustainable investments in the developing world. The proposal eventually failed to forge consensus due to fears that cheap avoided deforestation credits would flood the market and hinder emissions reductions in industrialised countries. Moreover, governments were concerned about a potential lack of permanence of deforestation-based carbon savings which can be annulated through deforestation at a later stage or forest fires. Thus, the Kyoto Protocol only allows afforestation and reforestation CDM projects. But convoluted rules have so far almost entirely hampered project development in the forestry sector – only one project has been initiated to date (Boyd et al. 2007).

By contrast, the current debate centres on ***national-level*** **compensation** for Reduced Emissions from Deforestation (RED), and in some cases also Degradation (REDD), i.e. industrialised countries would provide funds for developing nations which show a net reduction of deforestation rates compared to a reference level or maintain low deforestation rates. Accounting for changes on the national level is expected to reduce the danger of mere displacement of emissions, also known as leakage. While the problem of permanence still exists, it is increasingly recognized that temporary carbon storage is also valuable as an insurance against catastrophic events (Roe et al., 2007).

The list of arguments in favour of a national compensation scheme is long:

- Considering that tropical forests are often cleared for meagre agricultural returns – in Africa these can be as low as US$ 200 per hectare – while the released carbon might be as valuable as US$20,000 on a carbon market with a price of US$20 per tonne CO_2 saved, it is economically efficient to channel carbon funds to forest protection efforts (Chomitz et al., 2007).
- Substantial co-benefits for biodiversity, the local climate, the water cycle and sustainable development could result.
- Comparatively cheap RED credits could increase the chances for an ambitious reduction target at the international level.
- The potential of income generation through RED might incentivise developing countries to take on some form of reduction target – even if voluntary.

- Developing country participation, in turn, could ease the integration of the US into a Post-Kyoto agreement (Ebeling, 2006).
- A RED mechanism would provide the incentive to create forest monitoring infrastructure in tropical countries, possibly with financial support from donor countries.
- Measures to reduce deforestation could potentially serve mitigation of and adaptation to climate change at the same time, e.g. by promoting sustainable management practices such as agroforestry or the replanting of mangroves which provide buffer against coastal hazards (Roe et al., 2007).

Since the Coalition of Rainforest Nations (CRN) under the leadership of Papua New Guinea and Costa Rica reinitiated the debate with a submission to the 2005 UNFCCC Conference of the Parties (COP), several nations have formulated RED proposals, notably the forest nations Brazil and Indonesia. Moreover, researchers have supplemented the debate with more detailed suggestions on the implementation of potential RED or REDD schemes (Santilli et al., 2005; Archard and Belward, 2006). All proposals have in common that they suggest national level approaches based on voluntary participation of non-Annex I countries. Moreover, all schemes build on monitoring through remote sensing technologies. The proposals vary, however, considerably in regard to the scheme's set-up and, more importantly, the actors have different visions on the integration of RED into the existing architecture of the UNFCCC framework. Table 5 gives an overview on the differences between the existing proposals.

Table 5: Design and features of RED/REDD proposals

	Coalition of Rainforest Nation	**Brazil**	**Indonesia**	**Compensated Reductions**	**Joint Research Centre**
Scope	Deforestation	Deforestation	Deforestation and degradation	Deforestation	Deforestation and degradation
Reference Level	Historical	Historical	Historical and based on population density	Historical	Average global conversion rate and historical national conversion rate
Reward for low-emitting countries	Not considered	No	Yes	Yes	Yes
Baseline Adjustment over time	Not considered	Yes	Not considered	Downward (more stringent)	Downward (more stringent)
Liability/ Permanence	Banking, borrowing and insurance	Borrowing	Delineation of targeted forests, temporary credits	Banking, borrowing and insurance ("once in, always in" clause)	Temporary credits
Form of agreement	Open	Separate Protocol	New mechanism under KP	KP	Not considered
Financing	Regulated carbon markets	Voluntary Fund by Annex I Parties	Market and non-market options	Regulated carbon markets	Not considered
Units created for trade	Not considered	No trade, incentives for temporary storage	Annual or periodical credits	Certified emission reductions	Temporary certified emission reductions

Source: Elaboration of the authors based on Dutschke and Wolf, 2007 and Skutsch et al., 2007.

In potential negotiations, the decisions on both the *scope* of a RED scheme and the calculation of national *reference levels* against which to measure reductions of the deforestation rate will be highly controversial since they will determine which countries will benefit from the mechanism. Compensating for reduced deforestation and degradation widens the range of potential beneficiaries to include countries with comparably low deforestation rates (Griffiths, 2007). Likewise, a reference level which is set according to a benchmark system – the JRC (Joint Research Centre) has proposed to reward the maintenance of forests cover above the average global conversion rate of forests to other land uses – would increase the number of benefiting countries compared to a system where the reference level is based solely on historical rates of deforestation. This is because some countries like the Republic of Congo, Cameroon or Costa Rica currently have relatively low rates of deforestation but nonetheless remaining forest to protect. Reference level setting therefore offers the possibility to *reward low-emitting countries* and, at the same time, increase the attractiveness of participation in a RED mechanism (Dutschke and Wolf, 2007, Ebeling, 2006). Baselines could be adjusted downwards over time so as to make them more stringent.

Another open question is how the system would ensure *permanence of emissions savings*. The Coalition of Rainforest Nations (CRN)[45], Brazil as well as Santilli and colleagues (2005) have proposed a banking mechanism. Not all carbon reduction credits would become available for sale after the end of the accounting period. A certain share would remain in the countries' account as an insurance against above-baseline emissions in a future period. Alternatively, the JRC proposes that RED credits should be considered as merely temporarily preserved carbon. This raises the question of how these temporary credits would be integrated into the existing carbon markets. Some commentators suggest conversion rates between RED credits on the one hand and the allowances of current trading schemes on the other hand (Benndorf et al., 2007). The other option would be to develop *funding mechanisms* which are completely independent of the existing emissions trading schemes.

How much will it cost to substantially reduce tropical deforestation? Estimates vary widely (Roe et al., 2007; Krug und Köhler, 2007). It is clear that the costs will depend on the drivers of deforestation. Hence, reductions will be cheaper in Africa, where demand for fuelwood is the main driver, than in Asia, where timber extraction drives deforestation. Based on a review of estimates in the literature, Dutschke and Wolf (2007) conclude that a minimum of US$10 billion needs to be invested annually to save a substantial part of the world's forests.

Financing RED through carbon markets is not the only option. The UK, for instance, has proposed a tax on carbon-based extractive companies. Other options include a levy on air and maritime transport fuels or on the Kyoto mechanisms, while Brazil favours an international trust fund with voluntary contributions from industrialised countries (Dutschke and Wolf, 2007). The international community has, however, no good track record of equipping funds dedicated to a special issue on a voluntary basis and the financial leverage risks to be insufficient (Griffiths, 2007).

[45] See: http://www.rainforestcoalition.org/eng/

Overall, mixed funding seems to emerge as the best option (Griffiths, 2007; Ebeling, 2006). An international fund could provide the means for capacity building, the set-up of a carbon monitoring system as well as RED pilot schemes until countries are prepared to sell verified carbon credits to the regulated carbon markets. This requires, however, that a future RED scheme be linked with the Kyoto Protocol mechanisms in a way that allows trading with fungible credits. This would not be the case if a separate trading scheme for deforestation credits were set-up in a separate protocol to the UNFCCC, as proposed by Brazil.

If the Parties to the UNFCCC were to agree on the above described questions, two main concerns would remain in regard to national-level implementation:

- How can the international community ensure that the reduction of national deforestation rates is accompanied by *sustainable development benefits* for local and indigenous forest dwellers? Commentators have voiced concerns regarding the protection of traditional property and tenure rights and demand informed participation of all concerned groups in the design phase of a RED scheme as well as the equitable distribution of its benefits. Griffiths (2007) cites the danger of exclusionary conservation, of increased inequality and conflict between landowners and "landless" people, spreading corruption and land speculation in carbon-rich forest areas.
- How can *biodiversity co-benefits* be achieved through RED measures? If RED is financed through carbon credits, the level of carbon density, not its biodiversity value, will determine which forests receive protection. However, carbon density of forests does not strongly correlate with occurrence of biodiversity hotspots. Savannah forests, for example, would receive much less attention than rainforests since they yield lower carbon savings per hectare (Roe et al., 2007; Ebeling, 2006).

These and other questions will have to be addressed in the ongoing debate which is co-ordinated within the UNFCCC by the Subsidiary Body for Scientific and Technological Advice (SBSTA).[46] It will be supplemented with real world experience from pilot studies of the Forest Carbon Partnership Facility (FCPF), a World Bank initiative, which aims at testing the feasibility of carbon financing schemes.

[46] See Decision -/CP.13 on Reducing emissions from deforestation in developing countries: approaches to stimulate action.

4 SYNTHESIS, CONCLUSIONS AND RECOMMENDATIONS

This study has shown that much of the impact anticipated from climate change can be attributed to changes in water regimes. The simple summary is to say that this means in some places there will be too much water, in other places not enough; but the story is more complex – shifts in the timing of runoff due to early snow melt; increased annual average precipitation but falling in winter instead of during the growing season; interactions with rising CO_2 levels and temperatures that can benefit certain plant species, but only up to a point.

On balance there will likely be pronounced negative effects, with two distinctive features – geographic inequality, whereby some areas will be hit much harder than others; and a tendency for climate change to accompany other human-induced impacts like resource overexploitation, which are already the major cause of damage. Both factors represent a major challenge in building response strategies, as it means both that those less directly affected will need to be willing to assist those in most acute danger, and that the responses are not just fighting climate impacts, but also fundamental economic, social and historical trends that are well entrenched.

Preparing for and responding to climate impacts will require reviewing approaches to natural and managed ecosystems, for example through the lens of ecosystem services, by which greater emphasis is placed on the preservation of healthy ecosystems; and through sustainable agricultural and forestry practices that can lend to rather than working against climate resilience and species health.

The following table summarizes the impacts and responses noted in the paper.

Phenomenon	Impacts	Possible means to address
Flooding	Flood damage is on the increase in Europe, though largely due to poor planning and construction in vulnerable areas – however in future there is a likely increase in heavy precipitation leading to flash flooding, at both small and large scale.	• Technical flood protection • Allowance for higher flows/higher flood risk in flood defence structures • Natural retention of flood water • Restriction of settlement/building development in risk areas • Standards for building development • Improving forecasting and information • Improving insurance schemes against flood damage
Drought	Further declines in rainfall in Southern and Eastern Europe, causing severe water limitations.	• Technical measures to increase supply • Increasing efficiency of water use • Economic incentives • Restriction of water uses • Landscape planning measures to improve water balance • Improving forecasting, monitoring, information • Improving insurance schemes against drought damage
Drought	Cross-border conflicts over water	• European-level legislation and agreements • River and river-basin management schemes uniting upstream and downstream users.

Phenomenon	Impacts	Possible means to address
Natural ecosystem destruction and degradation	Reduction in biodiversity by changing suitability of habitats, in conjunction with fragmentation and human pressure; loss of ecosystem services like water retention and purification, carbon storage.	• Maintaining vegetative cover with native species, especially on sloping land. • Prevention of wetland and peatland drainage and conversion, and re-filling. • Establishment of connected habitats; planning for habitat shifts with future climate change.
Water shortages vs. greater precipitation, CO_2 and temperatures affecting Agriculture	In the South, more irrigation demand and subsequent impacts like over-abstraction and salinisation; in the north, more rain and higher temperatures and CO_2 concentrations could lead to rising yields, but also to more pests and disease and to greater evapotranspiration leading to harder rainfall.	• General measures as noted above for drought and flooding. • Efficiency improvement in irrigation management • Conservation tillage • Establishing native varieties to promote regeneration • Water conservation • Changing crop types; creating new types
Deforestation and degradation	Climate change will affect forest health, but the main effects are the loss of adaptive and mitigative capacity deforestation represents: standing forests contribute to buffering the impacts of climate change, while sequestering carbon. The main challenge of deforestation is the interrelation with economic and social drivers.	• Protection of property rights • Improved land-use planning • Reducing illegal logging • Economic incentives for standing forests • Certification • Ecotourism and non-timber products • Payments for ecosystem services schemes • Inclusion in effective international agreements

Conclusions and recommendations

Climate change impacts will be large: taking just one impact as an example, the anticipated reduction in water availability due to climate change will, in some European countries and under some scenarios, be larger than total current use for the agriculture, industry and domestic sectors combined. Those countries already facing water deficits will see worsening impacts, so that plans to meet deficits must be robust enough to meet not just current but long term needs.

Average future changes are less important than specific changes: even where there may be increases in precipitation or no change in the frequency of storms and other events, it is the timing and nature of these events that is of most importance to prepare for: we can anticipate shifts from summer to winter rain, toward shorter more intense precipitation, and more intense storms.

Given differential and cross-border impacts, cooperation and conflict avoidance will be essential: water is the most likely source of conflict, with different sectors and countries vying for resources that will in many places become scarcer; there is also the potential for competing policies like promotion of water-consuming biofuels. Good examples of river basin management in Europe should be extended elsewhere, as well as an integrated view of climate policy.

Natural ecosystems are both vulnerable to climate change and under pressure from human exploitation: natural ecosystems from mangroves to tundra are increasingly understood to provide valuable ecosystem services when they remain healthy, but still too often they are valued only in terms of exploitable resources and land area. Preserving them has multiple benefits, including in the fight against climate change, as barriers to impacts and as carbon sinks.

Agriculture is the largest single water user in Europe, and hence vulnerable: drought will increase where irrigation is already prevalent, making provision of water that much more difficult, while many rain-fed areas would need to convert to irrigation, at great cost. The result will likely be the loss of arable land.

Forests are important ecosystems to preserve, particularly in the tropics, which should be of global concern: the range of ecosystem services provided by forests is impressive, but their commodity value and land area make them attractive for short-term gain. The economics and politics of their preservation is a challenge and has been for many years, meaning new approaches, including through international agreements, must be tried before it is too late.

There are responses in each of the affected areas: as indicated in the synthesis table, above, adaptive responses are varied and will be effective – many represent best practices that would be wise even absent climate change, and their introduction could well be more than simply a defensive action, but an improvement.

European legislation is increasingly relevant, with many existing opportunities for improvement: legislation on water, water scarcity, flooding, the green paper on adaptation, reform of the CAP: all represent opportunities to address these issues. In general they are frameworks that do not mandate solutions directly yet, but could do so in further consultation and amendment. Leaving responses to climate impacts in the current vague terms, however, would be a serious setback with real negative implications for the future.

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6 ANNEX: PROJECTED IMPACTS OF CLIMATE CHANGE ON ARABLE, PERMANENT CROP AND LIVESTOCK SYSTEMS

Sector	Specific Crop	Effect of Increased Temperature	Effect of Increased CO_2	Impact on Geographic Distribution
Cereals	Wheat	Temperature increase will shorten length of growing season, reducing yields (since determinate species[47]).	Large yield increase due to C3 species outweighs negative temperature effect. Predict increase of 9-35% of wheat yield across Europe by 2050 (Maracchi et al.., 2005).	Expansion of cereal cultivation northwards (Harrison et al., 1995). Largest increases in yield expected in southern Europe, especially northern Spain, southern France, Italy and Greece (EEA, 2004). The drier conditions and increasing temperatures in the southern Mediterranean, such as southern Portugal and southern Spain, may lead to lower wheat yields and the need for new varieties and cultivation methods to maintain cereal production.
	Maize	Increased temperatures, particularly in the southern regions will decrease yield due to shorting growing season.	Small effect due to C4 species.	Increases in yield for northern areas, decreases in southern areas.
Seed Crops		Temperature increase will shorten growing periods of determinate species.		The cropping areas of cooler season seed crops, such as pea, faba bean and oil seed rape, may expand northwards into Fenno-Scandanavia, leading to an increased productivity of seed crops but reductions in yield elsewhere (Maracchi et al., 2005). Similarly, a northward expansion of warmer season seed crops such as soybean and sunflower is expected.

[47] Determinate plant species do not continue to grow indefinitely at the apex, but terminate in a flower. Their time to maturity depends on temperature and day length, and increased temperatures will shorten the length of the growing season, reducing yields.

Sector	Specific Crop	Effect of Increased Temperature	Effect of Increased CO_2	Impact on Geographic Distribution
Vegetables		Increased temperature will reduce the duration of crop growth and hence yield in determinate species, such as onion. An extended growing season will increase the duration of growth of indeterminate species, such as sugar beet, if enough water is available. For cool season vegetable crops such as cauliflower, large temperature increases may decrease production in southern Europe during the summer.	Root and tuber crops likely to show a large response due to underground capacity to store carbon and apoplastic mechanisms of phloem loading (Maracchi et al., 2005).	For field grown vegetables, increasing temperatures may expand production northwards.
Perennial Crops	Grapevine	This woody perennial responds readily to high temperatures.	May strongly stimulate yields without causing negative repercussions on grape or wine quality.	Increased temperatures and CO_2 will expand the potential growing area northwards and eastwards. However, yield variability will increase, implying economic risk.
	Indeterminate energy crops, e.g. *Miscanthus*	Favoured by conditions that extend the growing season and increase the light or water use efficiencies. For willow production in the UK, a temperature increase of 3^{o}C may increase yields by up to 40% (Olesen and Bindi, 2002).	Increases water use efficiency.	

Sector	Specific Crop	Effect of Increased Temperature	Effect of Increased CO_2	Impact on Geographic Distribution
Livestock Systems	For livestock systems, climate change may have both positive and negative impacts. Increased temperatures and the likelihood of extreme weather events may increase the need for animal housing; prolonged dry weather may increase the need to supplement forage with bought-in feed, silage or forage, potentially increasing feed costs; changes in global feed markets may affect costs; increased variability in grazing regimes due to wetter soil in autumn/winter; increases in disease – e.g. spread of Bluetongue into Northern Europe (Purse et al., 2005). Climate change could herald a shift into feedlot systems where temperature can be controlled and waste more easily used to generate energy – i.e. the collection of manure for use in biogas production (for example, Farming Futures, 2007). However this would have animal welfare implications as well as effecting biodiversity since it would reduce grazing and may impact adversely on HNV (High Nature Value) farming systems.			

ABBREVIATIONS

BRANCH	**B**iodiversity **R**equires **A**daptation in **N**orth West Europe under a **CH**anging climate
CAP	Common Agricultural Policy
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CIS	Common Implementation Strategy (under the Water Framework Directive)
CRN	Coalition of Rainforest Nations
Defra	Department for Environment, Food and Rural Affairs
DOC	Dissolved Organic Carbon
EEA	European Environment Agency
EAFRD	European Agricultural Fund for Rural Development
ECCP	European Climate Change Programme
ETBE	Ethyl Tertiary Butyl Ether
FAME	Fatty Acid Methyl Esters
FCPF	Forest Carbon Partnership Facility
FES	Forest Stewardship Council

FLEGT	(Action Plan for) Forest Law Enforcement Governance and Trade
GEF	Global Environment Facility
GTZ	Gesellschaft für Technische Zusammenarbeit
HNV	High Nature Value
ICPR	International Commission for the Protection of the Rhine
IGBP	International Geosphere-Biosphere Programme
IHP	International Hydrological Programme
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
ITTO	International Tropical Timber Organisation
IWT	Inland Waterway Transport
JRC	Joint Research Centre
LDCF	Least Developed Countries Fund
MONARCH	Modelling Natural Resource Responses to Climate change
Mtoe	Million tonnes of oil equivalent
NAPAs	National Action Plans for Adaptation
NPP	Net Primary Productivity

OECD	Organisation for Economic Co-operation and Development
PES	Payments for Ecosystem Services
PFM	Participatory Forest Management
RBMP	River Basin Management Plan
REDD	Reduced emissions from deforestation and degradation
RD	Rural Development
RME	Rapeseed oil methyl ester
RMPs	Recommended Management Practices
SBSTA	Subsidiary Body for Scientific and Technological Advice
SCCF	Special Climate Change Fund
SOC	Soil Organic Carbon
SRC	Short Rotation Coppice
UBA	*Umweltbundesamt*
UNFCCC	United Nations Framework Convention on Climate Change
VPA	Voluntary partnership agreement
WFD	Water Framework Directive