MACIS

Minimisation of and Adaptation to Climate change Impacts on biodiverSity

Deliverables 2.2 and 2.3:
Meta-analysis of adaptation and mitigation measures across the EU25 and their impacts and recommendations how negative impacts can be avoided

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Mitigation measures and adaptation measures and their impacts on biodiversity

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1. Introduction to mitigation, adaptation and biodiversity

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1.1 Introduction to MACIS

MACIS (Minimisation of Adaptation to Climate Change Impacts on Biodiversity) has reviewed the existing projections of climate change impacts on biodiversity (Olofsson et al, 2008). It is also assessing the available options to prevent and minimise negative impacts for the EU25 up to 2050 and review the state-of-the-art on methods to assess the probable future impacts of climate change on biodiversity. It includes this review of possible climate change adaptation and mitigation measures and their potential effect on future biodiversity. MACIS is also developing a series of biodiversity and habitat models that address biodiversity impacts, and are capable of calculating the consequences of the changes in the trends in drivers (WP3). The policy options at EU, MS, regional and local levels to prevent and minimise negative impacts from climate change and from climate change adaptation and mitigation measures are being explored (WP4).

1.2 Projected Climate Changes

The Intergovernmental Panel on Climate Change (IPCC) suggest that warming of the climate system is unequivocal, as is shown by observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, rising global average sea level and changing patterns and frequencies of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (IPCC, 2007a). For the next two decades, a warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. The best estimate for the low greenhouse gas emission scenario (B1) is 1.8°C (likely range is 1.1°C to 2.9°C), and the best estimate for the high scenario (A1FI) is 4.0°C (likely range is 2.4°C to 6.4°C) (IPCC, 2007a). The greatest temperature increase is projected to occur over land and at high latitudes in the northern hemisphere and snow cover and sea ice are projected to decrease (IPCC, 2007a). Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions (IPCC, 2007a).

In Europe, by the end of the century climate change could lead to an increase in annual mean temperatures, of between 2.5 to 5.5°C under a high greenhouse gas emissions scenario and between 1.0 to 4.0°C under a low greenhouse gas emissions scenario (IPCC, 2007a), although in the Russian Federation and other EECCA and SEE countries it could be more than 6°C (EEA, 2007). This warming would be greatest in winter in Eastern Europe and in summer in western and southern Europe (Giorgi et al., 2004). Projected precipitation changes are more variable, but most scenarios suggest an increase in mean annual precipitation in northern Europe and decreases further south, but with seasonal variations, although Turkey is projected to have up to a 50% increase by the 2080/2100 (EEA, 2007). Winter precipitation, for example, could increase in northern and central Europe, but decrease in Mediterranean Europe, while summer precipitation could decrease almost everywhere (Giorgi et al., 2004; Räisänen et al., 2004). Sea-level rise could be as much as 88 cm under a high greenhouse gas emissions scenario, and as low as 9 cm under a low greenhouse gas emissions scenario. Regional departures from these global rises could be ±50%, and additionally uplift/subsidence needs to be considered to developed relative sea-level rise scenarios (Hulme et al., 2002). Thus there is geographic variability in the exposure to climate change. Projections of temperature and precipitation extremes are highly uncertain, but warm periods, including heat waves, are expected to be more intense, more frequent and longer-lasting (Christensen and Christensen, 2007). These changes are projected to occur especially in the Mediterranean and eastern Europe, while cold winters are projected to disappear almost entirely from Europe by the end of the century. The probability of extreme precipitation events is projected to increase in western and northern Europe (Palmer and Raisanen, 2002), while many parts of Mediterranean Europe may experience further reduced rainfall and longer periods of drought (Good et al, 2006).

Observations from all continents and oceans show that many natural ecosystems are responding to regional climate changes, especially increases in temperature (IPCC, 2007b). The responses include poleward and elevational range shifts of biota, phenological changes (the earlier onset of spring events, migration (Climate Research, 35, 5-180, 2007), and lengthening of the growing season), changes in species' abundance and in community composition (IPCC, 2007b), as well as changes in form and physiology (Reading and Clarke, 1999), reproduction (Crick and Sparks, 1999) and productivity. This shows that some species are already adapting autonomously to current climate change, but it is also projected that the resilience of many species and ecosystems will be exceeded in the 21st century. These species may become vulnerable[1] if their adaptive capacity[2] is exceeded. This may be as a result of climate change or through a combination of this and associated disturbances or other drivers of global change and climate change has been identified as just one of the five major threats to biodiversity (Secretariat of the Convention on Biological Diversity, 2006).

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1 Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its *sensitivity*, and its adaptive capacity (Appendix 1 IPCC, 2007b).

2 Adaptive capacity is the ability of a system to adjust to *climate change* (including *climate variability* and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Appendix 1 IPCC, 2007b).

1.3 Mitigation and Adaptation

There are two main approaches to addressing the impacts of climate change: mitigation and adaptation. They are both aimed at reducing the vulnerability to climate change and both are viewed as necessary to reduce projected climate change and vulnerability. Mitigation and adaptation are often seen as complementary strategies for dealing with climate change in that both are necessary (Mata and Budhooram, 2007; Yohe and Strzepek 2007), but in economic terms they are substitutes and only become complementary when the adaptation costs depend on the amount of mitigation (Ingham et al., 2005). The relationship between mitigation and adaptation is complex, as the costs and benefits are not equally experienced between different actors or spatial and temporal scales (Wilbanks et al., 2003; Mata and Budhooram, 2007). This can make strategic planning and decision-making complicated. Wilbanks et al. (2007), for example, note that mitigation benefits are lagged in time, unlike some adaptation benefits (mitigation in one period produces long-lasting benefits for future generations while adaptation measures are often specific to a particular time-period), mitigation benefits are more global and adaptation benefits are more localised, and that mitigation focuses on greenhouse gas sources and sinks, while adaptation focuses on climate sensitive sectors and activities.

1.3.1 Mitigation

Climate change mitigation seeks a net reduction of greenhouse gas emissions, and also concerns the protection and promotion of carbon sinks, through land-use and habitat management. For example, two important habitats which can make a potentially significant contribution to carbon sequestration and storage are forests (Chapter 3) and wetlands (Chapter 6). Mitigation also involves the encouragement of the use of non-carbon or carbon-neutral energy sources (Chapter 5), and the improvement of energy efficiency. Mitigation, while often undertaken at the local level has global benefits, with possible ancillary benefits at the local or regional level (Adger et al., 2007). A review of the implications for biodiversity of mitigation measures concluded that they depended on their context, design and implementation, especially site selection and management practices (Gitay et al., 2002).

1.3.2 Adaptation

Adaptation is vital to avoiding unwanted impacts of climate change, especially in sectors, such as ecosystems, vulnerable to even moderate levels of warming, (Stern, 2006; IPCC, 2007a). It is also seen as a means maintaining or restoring of ecosystem resilience to single or multiple stresses (Convention on Biological Diversity, 2005). The IPCC recognises two types of adaptation: autonomous (or spontaneous) adaptation and planned (or societal) adaptation. In the case of biodiversity, the former occurs at the level of species and habitats and includes the various responses to climate change as have already been observed and the latter includes human management and policy actions aimed at facilitating adaptation. The underlying principles and a range of biodiversity adaptation strategies have been reviewed by Huntley (2007), but, where there is a lack of autonomous adaptive capacity, planned adaptation needs to be considered. Thus there is a need to review biodiversity policy at all levels to ensure that it is sufficiently robust and flexible to ensure that climate vulnerable biodiversity is adequately protected.

The IPCC suggested that adaptation practices can be differentiated along several dimensions by: spatial scale, sector, type of action, actor, climatic zone, baseline income/development level of the systems in which they are implemented or some combination of these and other categories (Adger et al., 2007). Generally adaptation measures are applied to particular (local) situations or sector(s) (Goklany, 2007), although they may have wider implications. Much adaptation research so far also has been sectoral and local, place-based (Klein et al., 2007) and this report examines some of the interactions between adaptation and mitigation measures in different sectors and with biodiversity (Chapters 2-9).

Also, it has been suggested that adaptation and development should not be viewed separately as they are often inter-related, as many adaptation measures are seen as part of sustainable development and there could be synergies (Ribot et al., 1996; Mata and Budhooram, 2007). Conflicts, however, are also possible. In the case of bioenergy crops, planting can conflict with food production (Chapter 2). The IPCC concludes its chapter on adaptation by suggesting that there is need for research on the synergies and trade-offs between various adaptation measures, and between adaptation and other development priorities (Klein et al., 2007). Halnaes and Verhagen (2007) argue that development programmes will be less effective when they overlook potential synergies and tradeoffs between development and climate change and that the effectiveness of development strategies may be reduced and sectoral vulnerability enhanced if climate change adaptation and mitigation are not taken into account.

The EU's Biodiversity Action Plan acknowledges the potential impact of climate change on global biodiversity, and wants to ensure that the relationship between climate change and biodiversity is fully recognised (European Commission 2008). It also recognises the central role biodiversity and ecosystems can play in reducing the impact of, and adapting to, climate change, for example in helping to reduce floods or absorb greenhouse gases. In addition, it wants Member States and the Community to “ensure that any mitigation and adaptation measures adopted to combat climate change do not impacts negatively on biodiversity.” (European Commission 2008, p23). The forthcoming White Paper on Adaptation will hopefully set out how this can be achieved and especially how adaptation can be mainstreamed.

1.3.3 Mitigation and adaptation: synergies, antagonisms and trade-offs

Mitigation should increase the ability of adaptation to reduce the likelihood of crossing critical thresholds of tolerable climate, but Yohe and Strzepek (2007) ask "By how much?". It is also possible that mitigation may make adaptation less effective in some circumstances or over certain time periods and, if climate change impacts are severe, adaptation may be inadequate despite high levels of mitigation (Yohe and Strzepek, 2007).

The need for both mitigation and adaptation and the possible synergies, antagonisms and trade-offs which can exist between them leads to a number of questions. These include: what is the optimal amount of adaptation and mitigation, when and which combination? (GAIM Task Force, 2002); are adaptation and mitigation substitutes or are they complementary actions? and what is the potential for creating synergies between the two responses? These are examined in Chapter 18 of the IPCC Fourth Assessment report (AR4), which also suggests that, at present, there is inadequate literature to provide clear answers, partly because of the separation of the adaptation and mitigation communities, who take use different approaches (Adger et al., 2007). It does, however identify four types of inter-relationships between adaptation and mitigation:

- Adaptation actions that have consequences for mitigation,
- Mitigation actions that have consequences for adaptation,
- Decisions that include trade-offs or synergies between adaptation and mitigation,
- Processes that have consequences for both adaptation and mitigation(Adger et al., 2007).

The implications of adaptation can be both positive and negative for mitigation and vice versa (Wilbanks et al., 2007). For example, afforestation that is part of a regional adaptation strategy also makes a positive contribution to mitigation. In contrast, adaptation actions that require increased energy use from carbon-emitting sources (e.g., indoor cooling) would affect mitigation efforts negatively.

The AR4 said "Considering the details of specific adaptation and mitigation activities at the level of regions and sectors shows that adaptation and mitigation can have a positive and negative influence on each other's effectiveness." (Adger et al., 2007, p757). It gives a number of supporting examples, especially in the supplementary material (Taylor et al., 2007) and develops a typology of the inter-relationships between climate change adaptation and mitigation (Figure 18.2, Adger et al., 2007). Wilbanks et al. (2007) give an example of the application of a modelling approach, based on the Climate Impact Response (CLIR) model which includes a dynamic optimization modelling procedure, based on estimates of the net present value of utility of consumption. This one of a few examples of the integration of both mitigation and adaptation and it supported the view that they are complementary, but are complexly related and they may reinforce or work against each other.

The AR4 also identifies that most adaptation and mitigation studies focus on their particular domain and few analyse the secondary consequences, such as the effects of mitigation measures on climate change impacts and adaption options (Adger et al., 2007). More importantly these studies do not examine the wider implications of these measures for other sectors. The AMICA project (Adaptation and Mitigation - an Integrated Climate Policy Approach) has developed three downloadable tools[3] to facilitate adaptation, mitigation and its integration on the local and regional level, with the last focusing on the inter-relationship between various energy, construction and spatial planning strategies and mitigation and adaptation benefits. Ecosystems are mentioned where they form part of one of the measures for dealing with an impact but there is no systematic treatment of biodiversity, and particularly the indirect effects of some of the measures upon it. The AR4, however, does say that "The most important link from mitigation to adaptation is through biodiversity, an important factor influencing human well-being in general and the coping options in particular (see MEA, 2005)." (Adger et al., 2007, p759).

1.3.4 Mitigation, adaptation and biodiversity

Biodiversity could be affected by adaptation and mitigation measures in many sectors and the aim of this report is to identify those climate change adaptation and mitigation measures which are most likely to have significant potential for adverse or beneficial impact on biodiversity, and to identify which habitat types and species groups are most at risk from these measures. This has been undertaken for eight key sectors: agriculture (Chapter 2), forestry (Chapter 3), energy (Chapter 4), built environment (Chapter 5), river and coastal flood management (Chapter 6), tourism and leisure (Chapter 7), health (Chapter 8) and conservation (Chapter 9) and where possible cross-sectoral issues have been noted. There is considerable variation in the amount and type of information that is available for each and this is reflected in the length of chapters and the research needs and gaps.

The sectoral results of both adaptation and mitigation measures and their impact on biodiversity are synthesised in the final chapter and possible synergies and antagonisms operating via biodiversity are identified (Chapter 10). These have already formed the basis of a paper, which showed that there are situations which are particularly negative or positive for these measures and biodiversity (Paterson et al., 2008). The cross-sectoral nature and impact of many of the measures are explored, reinforcing the strong commitment of the EU and some national Governments to an integrated environmental policy. This chapter also examines some of the uncertainties in the analysis and

[3] http://www.amica-climate.net/home1.html

identifies the research needs and gaps.

1.3.5 Policy context

Goklany (2007) argues that the most fruitful way of integrating adaptation and mitigation to climate change is through sustainable development and identifies what is needed to achieve this. The EU is strongly committed to integrated environmental policy and the environment is one of the three pillars of sustainable development. The final chapter, therefore, also briefly examines the policy context of mitigation and adaptation measures, especially those relevant to biodiversity and how policy can be used to achieve positive outcomes (Chapter 10).

1.4 Conclusions

One of the objectives of the UNFCCC (Article 2) is the ''stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner". For biodiversity this has three components: stabilization of greenhouse gas concentrations, which requires mitigation; a short enough time frame to allow natural adaptation and, implicitly, human planned adaptation through sustainable development. As has been shown above, mitigation and adaptation measures can be complementary, but their application needs to be integrated, given the synergies and antagonisms that can exist both within and between sectors, at different temporal and spatial scales. Care is needed, therefore, to ensure that the desired goals are achieved and where possible measures that are positive for mitigation and adaptation and biodiversity (win-win -win) are employed.

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2. Agriculture

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2.1 Introduction

This chapter examines the role of mitigation and adaptation in the agricultural sector and its impact on European biodiversity. It is divided into sections on livestock and poultry, crop production, management-based measures, fossil fuel use and political measures (although this will be covered in more detail in Work Package 4). Weiske's (2005) excellent and thorough review of mitigation strategies in agriculture provides a starting point and a basis for the analysis (although additional measures from other sources have been added). As the aim of this report was an overview of technically feasible mitigation measures in European agriculture, additional sources have been used to identify and discus adaptation measures. In many instances mitigation and adaptation strategies in agriculture are synergistic (Rosenzweig and Tubiello, 2007); for this reason, and to save repetition, they are not dealt with in separate chapters.

Although Weiske (2005) attempted a measure of 'environmental added value', he did not elaborate on how each measure could affect biodiversity. This report aims to expand on his efforts and provide examples of how each measure may have positive, neutral or negative outcomes. For each mitigation and adaptation strategy there is a short description of the measure and then a discussion of the known or likely affects on biodiversity. Often, the outcome for biodiversity will depend upon additional factors such as location, exact management prescription or even timing (Iglesias et al., 2007); the analysis of the effects on biodiversity will reflect this by providing 'worst-case' and 'best-case' impacts. An additional risk assessment factor is included which combines likelihood of strategy adoption with the biodiversity impact rating.

The next few sections provide a brief background to climate change, mitigation and adaptation before the analysis of biodiversity impacts.

2.2 Climate change in Europe

The predicted changes in climate vary across Europe although there are general patterns that emerge; Iglesias et al. (2007) summarised the climate change predictions:

- Temperatures will rise across Europe, especially during winter.
- Annual total precipitation may increase, but so will inter-seasonal variability and evapotranspiration.
- Summer rainfall is likely to be lower throughout much of Europe, with

periods of intense rainfall becoming more common and less winter precipitation falling as snow.

- Although difficult to forecast, the incidences of extreme weather events are likely to increase in a warmer climate. This will mean more flooding, higher winds, destructive precipitation events and longer periods of drought.
- Sea level is predicted to rise by as much as 5m, resulting in the likely salinisation of water resources in coastal areas.
- Atmospheric levels of CO_2 and ozone will rise.

These changes will have implications for farmers across Europe although they will vary regionally. For example, modellers predict slightly higher arable and grassland crop productivity, although this pattern is mainly confined to northern Europe (Olesen and Bindi, 2002; Hopkins and Del Prado, 2007; Olesen et al., 2007) whilst Mediterranean regions will suffer yield reductions (Maracchi et al., 2005; Alcamo et al., 2007). Crops previously unable to be grown in northern latitudes also will extend their ranges northward (Alcamo et al., 2007; Easterling and Tubiello, 2007).

Overall, the future for farmers in northern European countries is altogether brighter than that of Mediterranean areas, particularly concerning animal and crop production, as they will be less vulnerable to climate change (Berry et al., 2006); however, the impacts will often be complex and interlinked with other pressures (e.g., pollution, soil erosion, socio-economic). For this reason it is important to respond to and plan for climate change in the context of other local, regional or national pressures (Fischer et al., 2005; Rounsevell et al., 2005; Tubiello et al., 2007). Whilst it is beyond the remit of this report to analyse all the pressures facing agri-biodiversity in Europe, where there are obvious relationships between other pressure, mitigation and adaptation, they will be included in the analysis.

2.3 Climate change mitigation in European agriculture

Agriculture is a major contributor to climate change globally although it also has significant potential to act as a sink for greenhouse gases (Smith et al., 2007c). The greenhouse gas emissions from this sector account for 10% of global emissions although 40% of global CH_4 emissions and 60% of N_2O comes from agriculture (Weiske, 2005). In Western Europe agricultural emissions account for 9% of total emissions (EEA, 2007) and are projected to decrease by 2020 (see figure 2.1: U.S. Environmental Protection Agency, 2006; EEA, 2007). This decline is due in part to falling livestock numbers but also better management of emissions through fertiliser use: further reductions are expected from an increase awareness and adoption of mitigation methods.

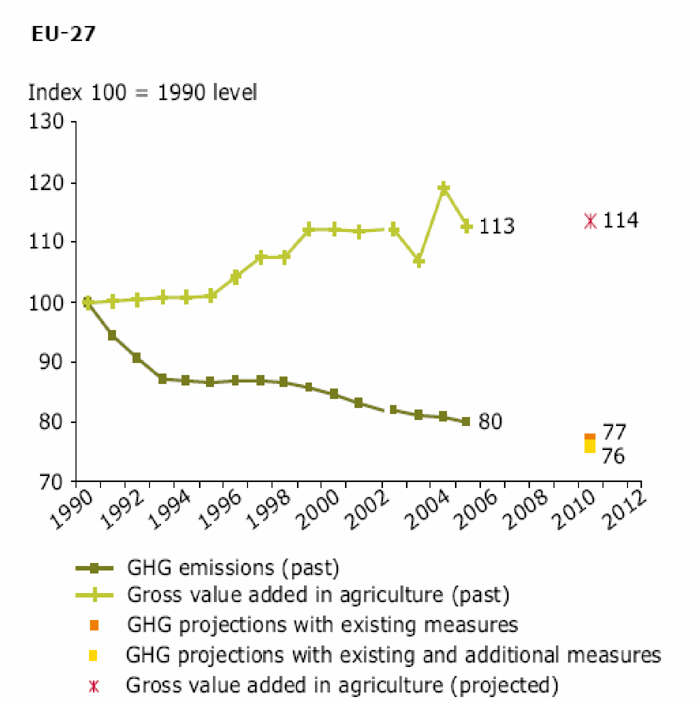


Figure 2.1: GHG emissions in EU27; source (EEA, 2007)

The three main GHG constituents from agriculture are (Smith et al., 2007c):

- CO_2, which is released from burnt or decaying plant and soil organic matter.
- CH_4, which comes from the anaerobic decomposition of organic matter (e.g., fermentation digestion in ruminants).
- N_2O, which comes from the transformation of soil and manure nitrogen by microbes.

Perhaps the most promising option for future reductions is to tackle the huge loss of carbon from croplands in European agriculture every year – a figure estimated to be in the region of 300 Tg C yr^{-1} (Janssens et al., 2003). Given that croplands are estimated to be the largest biospheric source of carbon lost to the atmosphere in Europe each year (Smith, 2004), the expectation on agriculture to adopt more mitigation measures is considerable. For croplands alone, the theoretical potential for carbon sequestration in the EU15 is estimated to be 90–120 tonnes C per year; although a more realistic figure is between 16-19 tonnes C per year, which could be achieved through various mitigation activities described in section 2.6 (Freibauer et al., 2004).

Whereas the mitigation potential for carbon depends upon the balance of enhancing removals and reducing emissions (i.e., the net change in the soil carbon pool), the mitigation potential for CH_4 and N_2O relies exclusively upon reducing emissions (Smith et al., 2007c). The potential for these gases is more difficult to estimate due to the complex nature of CO_2 mitigation measures. One estimate of recent (2000) emissions (in EU15) for CH_4 and N_2O is 383 tonnes CO_2 equivalents year^{-1} (Weiske et al., 2006) and mitigation potential estimates vary considerably. In the dairy sector alone (which represents the largest source of CH_4 and N_2O emissions), assuming a full adoption of possible mitigation measures, a GHG emission reduction of 50 tonnes CO_2 equivalents year^{-1} is possible (Weiske et al., 2006).

Agriculture, therefore, has huge mitigation potential and there are numerous strategies that have been employed or suggested (e.g., Paustian et al., 1998; Olesen and Bindi, 2002; Vleeshouwers and Verhagen, 2002; Choudhury et al., 2004; Falloon et al., 2004; Smith, 2004; Dale et al., 2005; Jones et al., 2005; Newman, 2005; Pattanayak et al., 2005; United States Environmental Protection Agency, 2005; Weiske, 2005; Amon et al., 2006; Clemens et al., 2006; Monteny et al., 2006; Schills et al., 2006; Smith et al., 2006; Wang and Dalal, 2006; Weiske et al., 2006; Hopkins and Del Prado, 2007; Hutchinson et al., 2007; Johnson et al., 2007; Lal, 2007b; Rosenzweig and Tubiello, 2007; Sirohi et al., 2007; Smith et al., 2007b; Smith et al., 2007c; Verchot, 2007; Verchot et al., 2007). To date, the most comprehensive report on mitigation in European agriculture has been Weiske's (2005) survey of technical and management-based mitigation measures in agriculture, which covers over 150 technological, managerial and institutional options. Section 2.6 follows Weiske's breakdown of strategy options with the addition of a few strategies to cover gaps; further adaptation strategies have also been added to Weiske's list.

Some of the measures will mitigate more than one gas (e.g., nutrient management in croplands), whilst others may have a positive mitigation effect on one gas but negative on another (e.g., reduced or no-tillage operations) (Weiske, 2005; Smith et al., 2007c).

2.4 Climate change adaptation in European agriculture

As stated in section 2.2, the predicted climate change effects will be considerable. Although there will be general climate patterns emerging across Europe, there will also be significant regional differences (Berry et al., 2006). In southern Europe, for example, coping with drought will be a more common occurrence than in northern Europe (Alcamo et al., 2007). Predicting the vulnerability of each region to climate change becomes paramount in order to provide the best options for response.

Planned adaptation strategies[4] are becoming increasingly important for society (Pielke et al., 2007). Our abilities to cope with changes in climate are

[4] "The increase in adaptive capacity by mobilising institutions and policies to establish or strengthen conditions" as opposed to autonomous adaptation, which is the application of experience and knowledge in reaction to climate change (Easterling and Tubiello, 2007).

enhanced if we are ready to adapt when the time arises. We are already seeing the development of planned adaptation measures for agriculture, e.g., breeding of drought resistant crop species (Parry et al., 2005); however, as much as we can plan adaptation strategies, the complex interactions between the biological, physical and societal factors concerned means that inevitably there will be unknown consequences of climate change which will require an element of autonomous adaptation (Tubiello et al., 2007).

For many farmers climate change may present new opportunities that will be readily adopted; in fact, agriculture is often seen as a highly adaptable industry (Burton and Lim, 2005) and this has given some commentators hope that agriculture will cope sufficiently well to maintain food production. This adaptive capacity, however, comes with the possibility that some measures may have environmental costs – here we aim to highlight these possible costs.

This report sets out to be as comprehensive as possible in describing all types of adaptation in agriculture whether planned or autonomous and draws from a burgeoning body of literature on the subject (see Kracauer Hartig et al., 1997; Karing et al., 1999; Rounsevell et al., 1999; Olesen and Bindi, 2002; Burton and Lim, 2005; Fischer et al., 2005; Hildén et al., 2005; Maracchi et al., 2005; Salinger et al., 2005; Wall and Smit, 2005; Berry et al., 2006; Conde et al., 2006; Alcamo et al., 2007; Easterling and Tubiello, 2007; FAO, 2007; Hopkins and Del Prado, 2007; Howden et al., 2007; Iglesias et al., 2007; Kotschi, 2007; McCarl, 2007; Rosenzweig and Tubiello, 2007; Verchot et al., 2007; Lobell et al., 2008).

2.5 Biodiversity in European agri-environments

The agricultural industry has had a major impact on biodiversity in Europe in the last fifty years due in part to an intensification of agricultural practices (e.g., use of pesticides, fertilisers, water), but also because agriculture is simply the dominant land-use type in much of Europe, impacting on most forms of natural or semi-natural habitats (Altieri, 1999; Stoate et al., 2001; Robinson and Sutherland, 2002; Donald, 2004; Donald and Evans, 2006; Reidsma et al., 2006; Butler et al., 2007; Henle et al., 2008).

Although attempts to halt the decline in farmland biodiversity (henceforth agri-biodiversity) have been attempted over the last few decades (Buckingham et al., 1999; Kleijn and Sutherland, 2003; Primdahl et al., 2003; Suarez et al., 2004; Bracken and Bolger, 2006; Kleijn et al., 2006) the future conservation of agri-biodiversity is still uncertain. The threat comes not only from agricultural practice, but from other land-use changes, soil erosion, air pollution, nitrogen desposition and climate change; whilst each threat on its own can cause great damage, the potential for simultaneous threats compounding the negative effect should not be underestimated.

Climate change is expected to have direct impacts on agri-biodiversity as well as on the animal and crop species agriculture depends upon (Berry et al., 2006; Menzel et al., 2006; Tubiello et al., 2007). Furthermore, many of the measures that farmers will be forced into taking to combat climate change may themselves have negative effects on biodiversity. Despite predictions that future global land-use changes will result in conversion from other land uses to agriculture to meet food supply demands (Tilman et al., 2001), in Europe it has been argued that with continued technological advances in agriculture maintained and food demand remaining constant, agricultural land will decline by as much as 50% (Rounsevell et al., 2005). This scenario poses considerable opportunities for European biodiversity with the potential to create semi-natural habitats from land abandonment and possibly even corridors to aid species dispersal (Donald and Evans, 2006). Whether this prediction is borne out will no doubt depend upon many socio-economic and political factors that are difficult to foresee.

What is clear, though, is that there are numerous avenues for mitigation and adaptation that will have positive and negative effects on biodiversity - this report attempts to highlight all measures from the obvious and likely to the less apparent and improbable.

Although this report explicitly examines the effects on biodiversity per se (and is important in its own right), there is also an increasing understanding that agri-biodiversity delivers vital ecosystem services necessary for human well-being (Robertson and Swinton, 2005; Schroter et al., 2005; Tscharntke et al., 2005; Bennett and Balvanera, 2007; Jackson et al., 2007); indeed, conserving biodiversity may even be vital for increasing human resilience and adaptation capacity in the face of climate change (Jackson et al., 2007).

Weiske (2005) provided an assessment of 'Environmental Added Value' in his report with occasional reference to biodiversity; the aim of the next section is to expand on these assessments (and in some cases disagree) focusing specifically on biodiversity. Attempts to either quantify known effects on biodiversity using existing literature or likely outcomes based on expert knowledge are provided.

2.6 Agricultural measures for mitigation and adaptation and their effects on biodiversity

All mitigation measure descriptions are after Weiske (2005) unless otherwise stated. Citations are given for adaptation strategies from various sources.

2.6.1 Livestock and Poultry

Animals in agriculture are the most important sources of CH_4 and N_2O emissions of any sector. The rumens of sheep and cattle, flatus from monogastric animals as well as manures are the most important CH_4 sources, whereas N_2O is mostly derived from nitrogen fertiliser, manure applications and urine (Monteny et al., 2006).

Reducing CH_4 emissions from animals can be achieved in a number of ways outlined below, but primarily these methods relate to increasing growth rates and milk yields or improving the longevity of dairy cow production (the number of lactation periods), i.e., increasing the ratio of productive capacity to non-productive (e.g., dry periods in dairy cows). Other methods relate to controlling emissions from manures and slurries, nitrogen management (Schills et al., 2006) and reducing enteric emissions from cattle through feeding strategies (Monteny et al., 2006).

Livestock and poultry farmers will also have to adapt to climate change. In northern European countries most livestock will adapt fairly well (Parsons et al., 2001), with possible advantages for many livestock farmers (e.g. lower heating costs in winter, reduced feed costs, increased survival) (Iglesias et al., 2007). However, increased frequencies of extreme events like droughts, floods and storms will have direct and sometimes catastrophic effects on livestock (Tubiello et al., 2007). Hot summers can cause heat stress, reducing productivity, reproduction and increasing mortality in cattle (Jordan, 2003; West, 2003; Brown-Brandl et al., 2006; Collier et al., 2006; Kendall et al., 2006; Nienaber and Hahn, 2007).

Furthermore, indirect effects through changes in pest and pathogen abundances will result in greater use of veterinary treatments for animals. Forage and pasture productivity will vary across Europe, in northern latitudes there is likely to be a slight increase in productivity but in many parts of southern Europe the opposite effect is more likely.

Wetter winters will result in livestock spending longer periods in housing to prevent poaching of waterlogged fields although longer growing seasons may result in higher grass silage yields (Iglesias et al., 2007).

2.6.1.1 Animal breeding and husbandry

2.6.1.1.1 Livestock breeding

Mitigation measure: Breeding for improvement of feed and reproductive efficiency as well as improved growth rate, i.e., increased output for lower input; however, it has been noted that cattle bred for improved productivity are more susceptible to heat stress (Nienaber and Hahn, 2007).
Adaptation measure: Breeding for improving heat tolerance (Jordan, 2003; Nienaber and Hahn, 2007).
Impact on biodiversity: No effect.

2.6.1.1.2 Breed choice

Mitigation measure: There are many different breeds of cattle, pigs, and sheep with varying levels of growth rate, milk production etc. The choice of the most productive breeds would be seen as a mitigation measure.
Adaptation measure: Choice of breeds that are more adaptable or tolerant of climatic extremes (Jordan, 2003; Brown-Brandl et al., 2006).
Impact on biodiversity: No effect. Although it has long been thought that traditional breeds of cattle were better for unimproved grassland managed for biodiversity than commercial breeds, recent research has shown that choice of breed makes little to no difference for plant or invertebrate diversity (Dumont et al., 2007; Isselstein et al., 2007; Scimone et al., 2007; Wallis De Vries et al., 2007; Hessle et al., 2008).

2.6.1.1.3 Transgenic improvements

Mitigation measure: Improve production and disease resistance by introducing 'new' or modified genes and DNA fragments into livestock (Maga, 2005; Wheeler, 2007).
Adaptation measure: Improves disease resistance (Maga, 2005; Wheeler, 2007).
Impact on biodiversity: No effect.

2.6.1.1.4 Artificial insemination

Mitigation measure: Increase productivity, a common practice in dairy farms, by allowing the selection of the best genetic material to improve milk yield in the herd.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.1.5 Planned selection of male/female at insemination (embryo and sperm sexing)

Mitigation measure: Increase productivity by allowing farmer to choose sex for desired outcome, e.g., female calves for herd replacements.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.1.6 Twinning

Mitigation measure: Increase productivity by ensuring that twins are produced instead of a single offspring.
Adaptation measure: Not applicable.
Impact on biodiversity: Negative – possible effects of increased grazing intensity in species-rich grasslands.

2.6.1.1.7 Lifetime efficiency (calves, cattle, cows / meat, milk)

Mitigation measure: Increasing productivity, for example, by increasing number of lactations per cow, use of bulls in preference to steers as they grow faster.
Adaptation measure: Not applicable.
Impact on biodiversity: Negative – possible effects of increased grazing intensity in species-rich grasslands.

2.6.1.1.8 Multiple use of cows (milk, calves and meat)

Mitigation measure: Current use of cattle is highly specialised – beef cattle are bred for meat, dairy for milk production. Combining dairy and beef production would reduce methane.
Adaptation measure: Not applicable
Impact on biodiversity: No effect.

2.6.1.2 Animal housing and in-barn manure management

New low-emission livestock and poultry housing systems
Mitigation measure: Reduces all GHG and NH_3 emissions compared to normal housing systems.
Adaptation measure: Would include better climate control to reduce heat stress (Jordan, 2003; Collier et al., 2006; Nienaber and Hahn, 2007.
Impact on biodiversity: Possible negative effect if replaces old, traditional buildings that are home to bats or nesting birds (e.g., barn owl) (UK Biodiversity Action Plan, 1994; Entwistle et al., 2001). Bats like to roost in roof voids, cervices, cracks, hollows and cavities that are likely not to exist in new buildings.

2.6.1.2.1 Natural ventilation

Mitigation measure: Reduces energy consumption (i.e., reduces GHG emissions); also may reduce NH_3 and N_2O.
Adaptation measure: To reduce heat stress.
Impact on biodiversity: Possible negative effect if installation interferes with roosting and nesting bat or bird species in old buildings (Entwistle et al., 2001).

2.6.1.2.2 Reducing the temperature of manure and the surfaces it covers

Mitigation measure: Reduces direct and indirect GHG emissions, although this may be partially offset by the energy required.
Adaptation measure: Not applicable.
Impact on biodiversity: Uncertain – changes to soil fauna and microorganisms are likely (probably compositional).

2.6.1.2.3 Purification of animal house emissions (filtration technologies)

Mitigation measure: Use of biofiltration, bioscrubbers and chemical scrubbers to reduce NH_3 emissions.
Adaptation measure: Uncertain – changes to soil fauna and microorganisms are likely (probably compositional).
Impact on biodiversity: Possible negative effect if installation may interfere with roosting and nesting bat or bird species in old buildings (Entwistle et al., 2001).

2.6.1.2.4 Tied systems instead of loose-housing systems

Mitigation measure: Animals are tied in portioned stalls to improve faces and urine hygiene, thereby reducing NH_3 and CH_4 emissions.
Adaptation measure: Not applicable.

Impact on biodiversity: No effect.

2.6.1.2.5 Cages and aviaries instead of floor systems for layer hens

Mitigation measure: Cages and aviaries reduce NH_3 emissions compared to floor systems where birds are kept on loose material.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.2.6 Reduction of manure contaminated surface areas

Mitigation measure: Decreases NH_3 volatilisation.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.2.7 Keeping surfaces, manure and animals dry

Mitigation measure: If bedding moisture is kept between 20 - 25%, CH_4 and NH_3 losses are reduced. Can be achieved by preventing water spillage (e.g., from drinkers) and proper ventilation systems. Manure drying requires significant energy use.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.2.8 Absorption of urine / Use of bedding material

Mitigation measure: The use of straw, sawdust, etc bedding is an effective method of reducing NH_3 emissions.
Adaptation measure: Positive – Disposal of beeding in fields with low organic matter contents will improve soil resilience.
Impact on biodiversity: Positive and negative – Disposal of bedding can alter soil microbial diversity composition. If applied in high fertility fields may reduce fertility to 'intermediate' status and hence encourage greater plant diversity; and vice versa, if applied to species-rich land may increase fertility and hence reduce plant diversity.

2.6.1.2.9 Slurry-based systems / Deep dung channels

Mitigation measure: NH_3 and CH_4 emission from stored slurry during storage can be reduced by making the slurry channels deeper and thereby reducing the surface area exposed to airflow.
Adaptation measure: Not applicable.
Impact on biodiversity: Possible negative effect if it requires major alterations to building design, which may impact on bats and birds in old farm buildings (Entwistle et al., 2001).

2.6.1.2.10 Rapid separation of faeces and urine

Mitigation measure: Rapid separation of faeces and urine has very good potential to reduce NH_3 emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: Requires additional equipment the use of which may disturb resident bats or birds in old buildings (Entwistle et al., 2001).

2.6.1.2.11 Partly or fully slatted floors

Mitigation measure: Slats that allow manure to fall through easily are effective at reducing NH_3 emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: Possible negative effect if installation requires major construction operations and could necessitate the construction of a new building. Installation may interfere with roosting and nesting bat or bird species in old buildings (Entwistle et al., 2001).

2.6.1.2.12 Frequent manure removal

Mitigation measure: Regular removal (washing or scraping) of manure will reduce NH_3 emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: Possible negative effect if construction of mechanical scrapers impact on resident bats and birds in old buildings (Entwistle et al., 2001). Additional problems from dirty water entering freshwater streams and rivers may occur from runoff or overland flow after field application. Nutrient loads cause eutrophication with harmful effects on stream and river biodiversity (Steinfeld et al., 2006); endocrine disruption in fish is also known to occur (Kolodziej et al., 2004; Orlando et al., 2004; Matthiessen et al., 2006; Milnes et al., 2006).

2.6.1.2.13 Extend housing duration over winter

Mitigation measure: Not applicable.
Adaptation measure: Wetter winters may result in livestock being housed for longer.
Impact on biodiversity: Possible negative effects stemming from lack of storage capacity for slurry and manures – overspill and runoff may enter watercourses. High nutrient loads cause eutrophication which have harmful effects on stream and river biodiversity (Steinfeld et al., 2006); endocrine disruption in fish is also known to occur (Kolodziej et al., 2004; Orlando et al., 2004; Matthiessen et al., 2006; Milnes et al., 2006). The alternative is to keep livestock outside which could result in major soil degradation from poaching (damage to soil in waterlogged conditions).

2.6.1.3 Grassland and grazing management

Adaptation of fertilisation on demand
Mitigation measure: Nutrient addition to grassland is synchronised with demand; this reduces GHG emissions by improving productivity.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive – excessive use of fertilisers is curbed, which will reduce the likelihood of the environmental damage to nutrient sensitive ecosystems like species-rich grassland, woodland and water courses (McLaughlin and Mineau, 1995; Heathwaite et al., 1998; Haygarth, 2005; Withers and Haygarth, 2007; Firbank et al., 2008).

2.6.1.3.1 Consideration of pasture age and composition

Mitigation measure: Re-improvement of pasture increases productivity by sowing improved varieties.
Adaptation measure: Not applicable
Impact on biodiversity: Negative – the improvement of unimproved grassland has been a major source of biodiversity loss in European grasslands. Replacing species-rich grassland with a sward of one or two varieties not only reduces plant diversity but insect, mammal and bird diversity as well (McLaughlin and Mineau, 1995; Wilson et al., 1999; Stoate et al., 2001; Robinson and Sutherland, 2002). Furthermore, replacing species-rich semi-natural grasslands by sown species-poor mixtures is also likely to impact the diversity and density of biocontrol agents, with flow-on effects to crop production and thus future pesticide use.

2.6.1.3.2 High sugar grasses

Mitigation measure: Grass varieties with higher sugar levels improve milk and meat productivity and increase nitrogen utilisation in the animal.
Adaptation measure: Not applicable.
Impact on biodiversity: Negative effects on biodiversity if sward is re-sown with high sugar varieties into unimproved grassland (McLaughlin and Mineau, 1995; Stoate et al., 2001; Robinson and Sutherland, 2002)..

2.6.1.3.3 Increase of N-fixation

Mitigation measure: Use of clover in sward reduces the need for N inputs from manure or mineral fertiliser, hence reducing NO_2 emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive and negative - increased N fixation will impact on the composition of soil communities (fauna and microorganisms). It is also likely to have flow-on effects on invertebrates (e.g. grasshoppers) by increasing their biomass and possibly modifying their species richness (although the direction of effects is hard to predict). Butterflies and pollinators will increase with increased abundance of legumes (Crews and Peoples, 2004).

2.6.1.3.4 Control groundwater level fluctuations

Mitigation measure: Fluctuating groundwater can result in increased N_2O emissions due to air in soil with high N_2O concentrations being driven out with rising water levels. Periodic drying and wetting of soils also promotes production and emission of N_2O. It involves irrigation and drainage control.
Adaptation measure: Adding drainage system to increase accessibility to grazing pastures after wetter winters. Irrigation maintains grass yield in drought summers.
Impact on biodiversity: Probably negative – improved drainage will increase nitrate leaching which could result in eutrophication and biodiversity loss in water courses (Heathwaite et al., 1998; Haygarth, 2005; Withers and Haygarth, 2007). Control of groundwater level fluctuations may decrease plant diversity in grasslands where fluctuating water levels combine with microtopography to provide a diversity of microhabitats, i.e. spatial heterogeneity that promotes

species coexistence. Also excessive water extraction from ponds or rivers may result in loss of biodiversity (Pimentel et al., 2004).

2.6.1.3.5 Conversion of arable land to grasslands

(Conversion of grassland to silvopasture or woodlands is discussed elsewhere)
Mitigation measure: Increase carbon sequestration through conversion to permanent plant cover.
Adaptation measure: If climate has become too extreme for crop production.
Impact on biodiversity: Positive and negative – conversion to 'species-rich' grassland will have benefits for invertebrate and bird populations (DEFRA, 2005b); introduction of grassland buffer strips also reduces risk of nutrient leaching and runoff into watercourses (Heathwaite et al., 1998; Haygarth, 2005; Withers and Haygarth, 2007). HoweveAt the same time, conversion of some arable lands may reduce biodiversity if they have been managed in a 'biodiversity-friendly' way, e.g., organic rotation with spring crops and other agri-environmental scheme prescriptions (Donald et al., 2001; Moorcroft et al., 2002; Bradbury et al., 2004; Hötker et al., 2004; Butler et al., 2005; DEFRA, 2005b; Gillings et al., 2005).

2.6.1.3.6 Cattle winter management

Mitigation measure: Taking cattle off grazing land in winter as N_2O emissions are highest and putting them on feed-pads where excreta can be collected and stored.
Adaptation measure: Wetter winters may force stock off grazing lands.
Impact on biodiversity: Positive – removing livestock from grazing land in winter is likely to reduce soil compaction and hence vegetation degradation in unimproved grasslands (Hamza and Anderson, 2005).

2.6.1.3.7 Planting fast-growing trees to provide shade

Mitigation & Adaptation measure: Heat stress reduces productivity (including milk yield), increases stress, discomfort and even mortality in livestock (Jordan, 2003; Nienaber and Hahn, 2007). Planting fast growing tree species (e.g., Populus spp) provides shade, which livestock readily use (Iglesias et al., 2007).
Impact on biodiversity: Positive or negative - the addition of trees may be beneficial to biodiversity by providing insect and bird habitats; on the other hand, if trees are planted in species-rich unimproved grassland they may reduce biodiversity by shading out the ground flora (Buscardo et al., 2008; Henle et al., 2008). Genetically diverse poplar stands will offer positive flow-on effects for soil microorganisms, insects ect.

2.6.1.3.8 Use of irrigation to maintain pasture productivity

Mitigation measure: Maintain growth rate in cattle.
Adaptation measure: Grassland productivity may be reduced due to drier summers resulting in food shortage for grazing animals (Jordan, 2003; Nienaber and Hahn, 2007).
Impact on biodiversity: Positive or negative effects: positive if irrigation

maintains species composition in unimproved grassland; negative if surface water runoff results in nutrient transfer and eutrophication of water courses (van Schilfgaarde, 1994; Heathwaite et al., 1998; Haygarth, 2005; Wichelns and Oster, 2006; Withers and Haygarth, 2007). Also excessive water extraction from ponds or rivers may result in loss of biodiversity (Pimentel et al., 2004).

2.6.1.3.9 Supplementary outdoor feeding

Mitigation measure: Maintain livestock productivity in drought conditions.
Adaptation measure: In drier summers pasture productivity may be reduced, whereby supplementary outdoor feeding may have to be adopted.
Impact on biodiversity: Possible localised negative effect in unimproved grassland if feed stations are not regularly moved; additional trampling may create bare ground areas and soil degradation which could lead to species loss (Hamza and Anderson, 2005) as well as increased pressure on remaining vegetation cover.

2.6.1.3.10 Reduced stocking rate

Mitigation measure: Not applicable
Adaptation measure: In drought years pasturelands will have lower yields which enforce lower livestock carrying capacity.
Impact on biodiversity: Positive or negative – in unimproved species-rich grassland neighbouring shrub or woodlands, a reduced stocking rate may not be an effective control of woody species invasion which is known to reduce herb and invertebrate diversity (Dolek and Geyer, 2002; Wallis De Vries et al., 2002; Woodcock et al., 2005). Alternately, if the original stocking rate was too high to maintain the optimum diversity of a sward, reducing it may be beneficial (Reidsma et al., 2006).

2.6.1.3.11 Relocation of pasture

Mitigation measure: Not applicable
Adaptation measure: In coastal or wet grazing pastures, increased sea-level rise or greater incidence of flooding may result in livestock being relocated to other pastures.
Impact on biodiversity: Neutral or negative - if livestock are relocated to join other livestock on unimproved pasture the increased stocking rate may degrade the sward and result in biodiversity loss (Isselstein et al., 2007; Jouven and Baumont, 2008).

2.6.1.4 Feeding strategies

2.6.1.4.1 Optimised plant and animal production

Mitigation measure: Growing feed for livestock on farm and recycling livestock manure as fertiliser for crops – reduces surplus nitrogen and may reduce N_2O and NH_3 emissions.
Adaptation measure: Reduce risk spread by having a greater diversity of crop and livestock systems.
Impact on biodiversity: Positive or negative – increasing landscape

heterogeneity on farmland is likely to have beneficial effects on biodiversity (Benton et al., 2003); however, starting a new farm enterprise may require new or modified buildings which could potentially result in habitat or species destruction.

2.6.1.4.2 Analysis of forage and fodder

Mitigation measure: Determining the quality of forage helps fine-tune the feed rations, thereby maximising efficiency and productivity.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.4.3 Improve forage quality

Mitigation measure: Increasing animal productivity reduces CH_4 emissions, i.e. forages that increase milk or meat production will decrease CH_4 emissions.
Adaptation measure: Increase or maintain livestock productivity under difficult climatic conditions.
Impact on biodiversity: Potentially negative – improving the forage quality in unimproved grassland would have negative effects for biodiversity (McLaughlin and Mineau, 1995; Stoate et al., 2001; Robinson and Sutherland, 2002).

2.6.1.4.4 Reduction of feed imports/More feed production on farm scale

Mitigation measure: Reduces GHG emissions from processing, transportation etc.
Adaptation measure: Increases resilience to climate change by having a greater diversity of crop and livestock systems.
Impact on biodiversity: Positive or negative - imported feedstuffs usually come from large, commercial farm units which can be farmed unsustainably (Fearnside, 2002; Donald, 2004; Naylor et al., 2005); a switch to home-grown pasture may be less damaging. Increasing the diversity of crop and livestock systems may also be beneficial (Benton et al., 2003); however, improving the forage quality in unimproved grassland would have negative effects for biodiversity (McLaughlin and Mineau, 1995; Stoate et al., 2001; Robinson and Sutherland, 2002).

2.6.1.4.5 Mechanical treatment of feed

Mitigation measure: Chopping, laceration or 'defibering' of forage is more efficiently digested by the rumen and hence reduces CH_4 emissions.
Adaptation measure: Improves quality of forage per unit of volume – may be advantageous during drier summers where forage yield is reduced.
Impact on biodiversity: No effect.

2.6.1.4.6 Chemical treatment of low quality feedstuffs

Mitigation measure: Increases digestibility of feedstuff by breaking down lignin. Also decreases proportion of feed energy converted to CH_4 from enteric fermentation.
Adaptation measure: No effect
Impact on biodiversity: Negative: spillage of chemicals in unimproved grassland may destroy sward.

2.6.1.4.7 Optimisation of livestock feeding/Adjusting livestock feed composition

Mitigation measure: Use of low nitrogen feed, increased amino-acid content of feed, increased use of concentrates, increased rumen efficiency by use of chemicals, invoking immune response to rumen protozoa, altering rumen bacterial fauna and genetic modification of rumen micro-organisms are all potential methods of reducing enteric CH_4 emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: Negative – changes in livestock feed may affect soil biodiversity if it affects the chemical composition of excreta.

2.6.1.4.8 Increasing animal productivity through the use of additives

Mitigation measure: Feed additives can reduce ammonia content and improve efficiency of production; they include the use of oils and fats, probiotics, enzymes, antibiotics, halogenated compounds, steroids, growth hormones (BST).
Adaptation measure: Maintain productivity when pasture and forage yields have been affected by climate change.
Impact on biodiversity: Neutral to negative – studies of the lifecycle of oestrogen hormones given to cattle have shown that fish species in nearby river systems have disrupted endocrine systems the consequences of which may be altered fish behaviour and reproduction (Kolodziej et al., 2004; Orlando et al., 2004; Mills and Chichester, 2005; Matthiessen et al., 2006).

2.6.1.5 Outdoor manure management (storage techniques)

2.6.1.5.1 Decreasing or eliminating the airflow across slurry and FYM

Mitigation measure: Reducing airflow reduces the amount of NH_3 given off, which can be achieved with windbreaks.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive – the addition of trees may be beneficial to biodiversity by providing insect and bird habitats.

2.6.1.5.2 Reducing the temperature of manure

Mitigation measure: Cooling reduces microbial activity, which reduces NH_3 emissions. This can be achieved by positioning store in shaded and windless location or with electrically powered cooling pipes in tanks.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect

2.6.1.5.3 Reducing the pH of manure

Mitigation measure: At pH 4.5 CH_4, CO_2 and N_2O losses are almost completely abated; NH_3 emissions are reduced significantly too.
Adaptation measure: Not applicable.
Impact on biodiversity: Possibly negative – changes to pH may affect soil microorganisms and othe roisl faunal diversity.

2.6.1.5.4 Manure additives

Mitigation measure: Organic and inorganic acids, enzymes and micro-organisms applied to manure of the land can reduce CH_4 and NH_3.
Adaptation measure: Not applicable.
Impact on biodiversity: Neutral to negative – if chemical additives get into watercourse it may have harmful effects on aquatic biodiversity as well as soil faunal diversity.

2.6.1.5.5 Reducing the surface per unit volume of slurry or FYM stores

Mitigation measure: CH_4 and NH_3 can be reduced (about 90% of manure's CH_4 potential and about 80% of NH_3-N can be lost to the atmosphere from open lagoons).
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.5.6 Mechanical separation of solids of manure

Mitigation measure: Use of vibrating screen, stationary sloping screen or pressure-roller mechanical separators to produce liquid and solid fractions. The liquid component has lower NH_3 and N_2O emissions after application.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.5.7 Composting of solid manure or slurry with added solids or of farm yard manure (FYM)

Mitigation measure: Can significantly reduce N_2O emissions in comparison to usual manure storage emissions; the drier the manure, the lower the methane emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive – risk of pollution of watercourse from run-off reduced (McLaughlin and Mineau, 1995; Heathwaite et al., 1998; Haygarth, 2005; Withers and Haygarth, 2007; Firbank et al., 2008).

2.6.1.5.8 Controlled denitrification processes in slurry

Mitigation measure: Transforming ammonium to nitrogen gas by controlled denitrification can reduce NH_3.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.5.9 Minimising of stirring

Mitigation measure: Allows the build-up of a natural crust on stored slurry with high dry matter content, thereby reducing NH_3 emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.5.10 Fill-pipe into manure storages underneath the slurry surface

Mitigation measure: If crust is developed (see above) can reduce NH_3 emissions.
Adaptation measure: Not applicable.

Impact on biodiversity: No effect.

2.6.1.5.11 FYM storage techniques

Mitigation measure: Increasing carbon content of FYM by compacting it, covering it with a flexible sheet and repeated turnover can reduce GHG emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.1.5.12 Anaerobic digestion

Mitigation measure: Bacterial fermentation of organic material under controlled conditions in a closed vessel which produces biogas (CH_4 and CO_2). Anaerobic digestion plants can be located on a farm and can be used to produce heat and/or electricity from the biogas, which can offset CO_2 emissions from fossil fuel.
Adaptation measure: Not applicable.
Impact on biodiversity: Neutral

2.6.2 Crop production

Crop systems allow farmers to mitigate GHGs in three main ways: reducing emissions, enhancing removals and avoiding emissions. These mitigation methods can be applied through agronomy, nutrient management, tillage and residue management, water management, land cover change, agroforestry, and rice management (Paustian et al., 1998; Smith et al., 2001b; Olesen and Bindi, 2002; Vleeshouwers and Verhagen, 2002; Smith, 2004; Ferrero, 2006; Wang and Dalal, 2006; Hutchinson et al., 2007; Johnson et al., 2007; Lal, 2007b; Rosenzweig and Tubiello, 2007; Smith et al., 2007b; Smith et al., 2007c).

Many crop production systems will have the ability to adapt to long-term climate as they have in the past, e.g., farmers have the ability to choose crops on an annual basis to cope with climate change (Burton and Lim, 2005). For many farmers in northern Europe, adaptation to climate change will result in higher crop yields; however, predictions of greater frequency of extreme events will be hard to adapt to and the expectation is that these events will reduce long-term yields of crops (Easterling and Tubiello, 2007). The use of irrigation, for example, is likely to increase, particularly in southern Europe or in summer droughts elsewhere (Alcamo et al., 2007).

There are many strategies in crop production systems that provide climate change mitigation and adaptation; some of these strategies also provide additional environmental benefits but as in animal production systems, this often depends upon the style of management and location.

2.6.2.1 Continuous plant cover (catch crops and intercrops)

Mitigation measure: Catch crops are usually sown after the harvest of one crop and before the sowing of the next. They offer forage or green manure (providing fertility for the soil thereby reducing nitrogen applications for the next crop) potential and are usually based on quick growing plants that will establish before winter. Catch crops can also be planted amongst the crop as in intercropping systems. Their mitigation benefits include reducing N_2O emissions or leachate, improving N-use efficiency and carbon sequestration in the soil.

Adaptation measure: Catch crops may offer adaptation benefits too: in winter floods they offer soil stabilisation and prevent erosion; potential reduction in increased pest populations (e.g., root nematodes in potatoes: Davies et al., 2007) through the use of allelopathic species that give off toxic chemicals (e.g., Tagetes spp. Kimpinski et al., 2000; LaMondia, 2006; Pudasaini et al., 2006); potential as a mulch to reduce water loss and provide an emergency forage crop in drought conditions (Verhallen et al., 2003; Wilke and Snapp, 2008).

Impact on biodiversity: Positive and negative – catch crops reduce nitrate leaching (Kirchmann et al., 2002), which can cause eutrophication in watercourses (Stoate et al., 2001; Crews and Peoples, 2004; Withers and Haygarth, 2007; Firbank et al., 2008). They can also provide cover for many farmland bird and insect species (DEFRA, 2005b) and reduce soil erosion which would have negative effects on local biodiversity (DEFRA, 2005a). However, if catch crops replace over-winter stubbles there could be a resulting loss of invertebrate and bird species (Wakeham-Dawson and Aebischer, 1998; Tella and Forero, 2000; Donald et al., 2001; Gillings and Fuller, 2001; Moorcroft et al., 2002; Robinson and Sutherland, 2002; Bradbury et al., 2004; Hötker et al., 2004; Butler et al., 2005; Gillings et al., 2005; Orłowskia, 2006; Whittingham et al., 2006; Gillings et al., 2007; Orłowskia and Czarnecka, 2007).

2.6.2.2 Optimisation of water management (irrigation, drainage)

Mitigation measure: Irrigation and drainage can improve productivity in the right conditions and in some circumstances reduce N_2O emissions.

Adaptation measure: As above, irrigation may be required in dry summers; field drainage may alleviate the worst effects of winter or summer flooding (Parry et al., 2005).

Impact on biodiversity: Neutral to negative – the negative environmental impacts of irrigation have long been known (increase surface water run-off, nutrient leaching and soil erosion, reduces water levels in rivers and causes salinisation of land and water) (van Schilfgaarde, 1994; McLaughlin and Mineau, 1995; Stoate et al., 2001; Zalidis et al., 2002; Allan, 2004; Wichelns and Oster, 2006; Gordon et al., 2008; Henle et al., 2008) which all indirectly affect biodiversity. Direct effects on biodiversity may also occur, e.g., in Spain the use of irrigation can affect the foraging and behaviour of the rare steppe birds (Brotons et al., 2004; Ursúa et al., 2005; García et al., 2006). Drainage of grazing marshland and other unimproved agricultural fields has caused severe loss of diversity also (Stoate et al., 2001). The creation of new reservoirs to cope with increased irrigation may have mixed benefits.

2.6.2.3 Prevention of soil compaction

Mitigation measure: Soil compaction reduces crop productivity, causes soil degradation and can increase emissions of N_2O. There are a number of options for preventing compaction including use of low ground pressure tyres or tracks on vehicles, avoiding wet soils and adding organic matter to soil.
Adaptation measure: Soil compaction will compound the effects of flooding by reducing water infiltration in soils; compaction-free soils are also more drought resistant for crops (Stoate et al., 2001; Sullivan, 2002; Hamza and Anderson, 2005)
Impact on biodiversity: Positive – reducing compaction will reduce the likelihood of water run-off and soil erosion, which can both have severe effects on biodiversity (Stoate et al., 2001; Zalidis et al., 2002); it will also increase levels of soil-borne fauna (McLaughlin and Mineau, 1995).

2.6.2.4 Reduced tillage or no-tillage

Mitigation measure: Reduced tillage operations will result in less fossil-fuel use and increases sequestration of carbon to the soil pool through less disturbance of organic matter in the soil.
Adaptation measure: Increases soil functioning ability (structure, water retention and nutrient cycling) by increasing organic matter content and reducing compaction (Holland, 2004; Lal et al., 2004; Hamza and Anderson, 2005; Lankoski et al., 2006; Lal, 2007a; Lal et al., 2007; Huang et al., 2008; Mondini and Sequi, 2008; Powlson et al., 2008); thereby improving soil resilience to climatic effects of drought and floods.
Impact on biodiversity: Positive and negative – soil biota levels usually increase with soil conservation methods like no-till (Stinner and House, 1990; Wardle, 1995; Lupwayi et al., 1998; Kladivko, 2001; Brennan et al., 2006; Joschko et al., 2006; Mondini and Sequi, 2008); reduced water run-off will lessen the likelihood of watercourse pollution and eutrophication from nutrients and sediments (Sharpley et al., 2000; Mickelson et al., 2001; Holland, 2004; Lankoski et al., 2006; Yates et al., 2006; Withers et al., 2007) and bird and mammal numbers can increase due to the presence of over-winter stubble habitat, crop residues and seed presence long after harvest (Holland, 2004; Field et al., 2007).

Conservation tillage systems have also been shown to have some negative effects, including: dissolved phosphorus runoff can increase because of an accumulation in the soil surface (Holland, 2004); run-off for herbicides also can be higher depending on the type used and the need to use more pre-emergence herbicides (Shipitalo and Owens, 2006; Warnemuende et al., 2007) and groundwater leaching may also increase (Holland, 2004; Lankoski et al., 2006). Slug levels also can be a problem in no-till systems which will result in additional pesticide usage (Hunter, 1967; Glen et al., 1989; Hammond et al., 1999). Finally, no-till systems lend themselves to using herbicide-resistant crops (Ammann, 2005; Service, 2007) – there is some evidence (but overall the evidence is inconclusive) that GM crops could have negative impacts on weed, invertebrate and bird diversity (Brooks et al., 2003; Haughton et al., 2003; Hawes et al., 2003; Heard et al., 2003a; Heard et al., 2003b; Roy et al., 2003; Butler et al., 2007).

2.6.2.5 Precision farming

Mitigation measure: Crop requirements are met exactly through the use of high technology (GPS yield mapping, variable rate delivery of seed, pesticides and fertilisers) at a very fine scale (a few square metres) and at the right tim; results in maximisation of efficiency of all inputs (including fuel).
Adaptation measure: Not applicable.
Impact on biodiversity: Positive – precision farming aims to reduce all inputs and target them exactly, reducing the risk of run-off, leaching, etc (Cassman, 1999; Robert, 2002; Bakhsh et al., 2005; Lerch et al., 2005; Mondal and Tewari, 2007); the technology can be applied to irrigation too with additional benefits for soil conservation (Sadler et al., 2005; Sudduth et al., 2007).

2.6.2.6 Changing from spring to winter cultivars (and *vice versa*)

Mitigation measure: Spring sown crops have potential to lower N_2O because they require lower nitrogen inputs than winter sown crops; although this advantage may be lost due to the presence of bare land over winter and the loss in overall productivity.
Adaptation measure: Spring cropping may increase as a consequence of wetter winters; alternately, winter crops may confer better drought tolerance due to larger root networks (Singh et al., 1997; Yau, 2007). Current spring crop sowing dates may have to be earlier to cope with heat stress in the summer (Tubiello et al., 2000), which may not be possible in wet late winters/early springs.
Impact on biodiversity: Positive or negative – the adoption of either spring or winter sown crops could have beneficial effects depending upon location and the addition of other management prescriptions. In western Europe, one of the main reason for agri-biodiversity loss has been the decline in spring cropping systems (Stoate et al., 2001; Robinson and Sutherland, 2002), which allow weed plants to persist over winter that are beneficial for invertebrates and ground-nesting birds (Wakeham-Dawson and Aebischer, 1998; Buckingham et al., 1999; Hald, 1999; Tella and Forero, 2000; Donald et al., 2001; Gillings and Fuller, 2001; Moorcroft et al., 2002; Hotker et al., 2004; Suarez et al., 2004; Butler et al., 2005; Gillings et al., 2005; Bracken and Bolger, 2006; Orłowskia, 2006; Gillings et al., 2007; Orłowskia and Czarnecka, 2007). Increasing the percentage of spring crops in Europe would likely enhance biodiversity.

2.6.2.7 Breed cultivars that improve N-use efficiency

Mitigation measure: Increases productivity by the use of crop genotypes that are better able to utilise nitrogen under low nitrogen conditions, resulting in lower N_2O emissions.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive - if lower nitrogen fertiliser rates are used the likelihood of eutrophication issues are reduced (Heathwaite et al., 1998; Haygarth, 2005; Withers and Haygarth, 2007).

2.6.2.8 Breed cultivars that improve drought resistance

Mitigation measure: Drought tolerance will increase productivity in crop species.
Adaptation measure: Increased incidence of drought may force the further development and use of drought tolerant crops (Parry et al., 2005; Tuberosa and Salvi, 2006; Toker et al., 2007; Vahisalu et al., 2008).
Impact on biodiversity: No effect.

2.6.2.9 Use of deep rooted crops

Mitigation measure: Smith (2004) suggests the use of deep rooted crops will sequester more carbon.
Adaptation measure: Deeper rooted crops may be more drought tolerant (Reynolds et al., 2007).
Impact on biodiversity: Uncertain - deep-rooted crops will strongly modify water dynamics in soils (and possibly thereby nutrients). This is likely to affect soil faunal diversity, and possibly plant diversity (e.g. species composition and diversity of weeds).

2.6.2.10 Use of genetically modified crops

Many of the techniques listed below are still in development but offer great potential for climate change adaptation and mitigation. The threat to biodiversity of these techniques is highly controversial and requires further risk assessment. Biodiversity effects are described together.

2.6.2.10.1 Herbicide resistant crops

Mitigation measure: The adoption of herbicide-resistant crop species (glyphosate is the main chemical but crops are being developed for other herbicides) reduces the number of herbicide applications required and increases productivity (Halford, 2004; Snow et al., 2005; Herdt, 2006; Behrens et al., 2007; Service, 2007); it also enables the successful adoption of no-till cultivation which enhances soil carbon.
Adaptation measure: In areas with water shortages, a reduction in spraying would be beneficial. The co-adoption of no-till measures would increase soil water retention.

2.6.2.10.2 Virus resistant crops

Mitigation measure: Some viruses (or their vectors) may increase in incidence with climate change (Olesen and Bindi, 2002); virus resistant crops will maintain productivity and reduce the use of chemical inputs (Halford, 2004; Snow et al., 2005).
Adaptation measure: Will be able to cope with a greater incidence of viruses.

2.6.2.10.3 Pest resistant crops

Mitigation measure: GM pest-resistant crops are already in use (Halford, 2004; Snow et al., 2005; Sanvido et al., 2007); they offer improvements in productivity as well as a reduction in other inputs.
Adaptation measure: The incidence of crop pest is likely to increase with climate change (Davies et al., 2007; Easterling and Tubiello, 2007; FAO, 2007); pest-resistant crops will enhance the ability of farmers to cope.

2.6.2.10.4 Fungal resistant crops

Mitigation measure: As for virus and pest, some crop fungal pathogens are likely to increase, or new ones will emerge (Davies et al., 2007; FAO, 2007). The development of fungal resistant crops will improve productivity and reduce the need of other inputs (Halford, 2004; Snow et al., 2005).
Adaptation measure: Enhance the ability of farmers to cope with increased incidence of new fungal pathogens.

2.6.2.10.5 Drought resistant crops

Mitigation measure: A number of developments for improving drought tolerance in crop species are being, or have been, made (Mitra, 2001; Ammann, 2005; Parry et al., 2005; Slafer et al., 2005; Herdt, 2006; Tuberosa and Salvi, 2006; Reynolds et al., 2007; Toker et al., 2007; Pennisi, 2008); improving productivity would be a useful mitigation measure.
Adaptation measure: Drought resistant crops would have an obvious benefit in warmer regions of Europe and will help adapt to the likelihood of increased drought incidence in the future.

2.6.2.10.6 Flood resistant crops

Mitigation measure: The development of flood resistant strains of crop species (Dennis et al., 2000; Cherian et al., 2006; Vij and Tyagi, 2007) will help to maintain crop productivity.
Adaptation measure: Increased incidence of floods throughout Europe (Alcamo et al., 2007) would mean the development of flood-resistant crops would offer huge adaptation capacity to farmers.

2.6.2.10.7 Salt tolerant crops

Mitigation measure: The future development of salt tolerant crops offers the potential to introduce crop production to degraded lands (often degraded by excessive irrigation) (Dale et al., 2002; Halford, 2004; Yamaguchi and Blumwald, 2005).
Adaptation measure: In semi-arid areas warmer summers and drought incidence may increase the use of irrigation which could result in soil salinisation (van

Schilfgaarde, 1994; Parry et al., 2005); therefore, salt tolerant crops could be grown.

Impact of GM crops on biodiversity: Possibly positive and/or negative – research on the effects of GM crops is still in the early stages and as yet there are no really conclusive outcomes; we outline below the possible negative effects in five main categories (Morris, 2007), but futher research is urgently required.

- A change in the invasibility of the crop through greater competitive ability (Dale et al., 2002; Andow and Zwahlen, 2006; Morris, 2007; Valosaari, 2008); this could have repercussions for neighbouring natural habitats with some native species being replaced by the invasive crop.
- Gene flow from crop species populations to populations of wild relatives (Dale et al., 2002; Snow et al., 2005; Andow and Zwahlen, 2006; Campbell et al., 2006; Morris, 2007; Sanvido et al., 2007; Schoen et al., 2008); this could result in losses of genetic diversity, reduced genetic fitness or increased genetic fitness (becoming invasive).
- Development of herbicide resistant weeds (Behrens et al., 2007; Morris, 2007; Service, 2007), which could result in the use of more aggressive and harmful herbicides to control them.
- Changes in soil ecology (Lilley et al., 2006) that may include effects on bacterial diversity, number and activity, fungal counts, effects on numbers of protozoa, nematodes and collembolan, diversity of nematodes, and woodlice mortality (the long-term effects are still uncertain and much research needs to be done).
- Indirect effects on wildlife – complete weed control in herbicide resistant crops has been shown to reduce weed diversity and consequently invertebrate and bird diversity (Watkinson et al., 2000; Brooks et al., 2003; Haughton et al., 2003; Hawes et al., 2003; Heard et al., 2003b; Roy et al., 2003; Ammann, 2005; Butler et al., 2007; Chamberlain et al., 2007).

However, the possible benefits of this measure are a reduced use of other herbicides which lowers the likelihood of chemicals entering watercourses (glyphosate, the main chemical used for herbicide resistant crops, breaks down on soil contact); also target-species specific insect-tolerant crops (e.g., Bt) can result in greater non-pest insect diversity.

2.6.2.11 Development of perennial grain crops

Mitigation measure: Perennial crops store more carbon than annual crops and do not require annual cultivation, thereby reducing GHG emissions from the soil (Cox et al., 2006; Jordan et al., 2007).
Adaptation measure: Greater water-use efficiency through established root network in perennial crops (Cox et al., 2006); the development of perennial wheat varieties for dryland cropping would have considerable adaptation

benefits for many farmers in southern Europe (Bell et al., 2008).
Impact on biodiversity: Positive – Reductions in soil erosion, nitrate leaching, run-off, eutrophication etc will be achieved with the adoption of perennial crops (Bell et al., 2008). Reductions in fertiliser inputs are also likely (Crews, 2005); however, unless development of perennial grain crops can approach the yield of annual grain crops more agricultural land may be needed elsewhere to meet demands, which may have consequences for marginal and semi-natural lands.

2.6.2.12 Use of N fixing crops

Mitigation measure: Reduces the amount of nitrogen fertiliser application thereby saving energy.
Adaptation measure: Improves soil structure which may confer increased environmental stress resistance (Jensen and Hauggaard-Nielsen, 2003).
Impact on biodiversity: Positive or negative – if lower nitrogen fertiliser rates are used the likelihood of pollution in watercourse is reduced (Jensen and Hauggaard-Nielsen, 2003; Crews and Peoples, 2004). The adoption of N-fixing crops (particularly grass/legume mixes) is the mainstay for organic farming systems and has been shown to improve levels of biodiversity (Giller and Cadisch, 1995; Hald, 1999; Hyvönen et al., 2003; Bengtsson et al., 2005; Fuller et al., 2005; Hole et al., 2005; Hyvönen, 2007) as well as improve soil structure and reduce soil erosion (Jensen and Hauggaard-Nielsen, 2003). However, positive benefits will depend upon management, e.g., the use of N fixing crops in specie-rich grassland woud reduce biodiversity.

2.6.2.13 Slurry, manure and fertiliser management

Precision crop nutrient techniques
Mitigation measure: The adoption of improved precision techniques - soil analysis, manure analysis, adaptation of fertiliser and pesticide application on demand, matching fertiliser to seasonal conditions, optimisation of split application schemes, slow and controlled release fertilisers, use of band placement machinery - are all designed to reduce needless applications.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive – can reduce leaching and the associated problems (eutrophication, etc) (Cassman, 1999; Robert, 2002; Bakhsh et al., 2005; Lerch et al., 2005; Mondal and Tewari, 2007).

2.6.2.13.1 Substituting inorganic by organic nitrogen fertiliser

Mitigation measure: The total amount of nitrogen in arable and grassland farm systems can be reduced by replacing inorganic fertiliser with organic fertiliser as well as reducing N_2O and NH_3 emissions.
Adaptation measure: Organic manure applications can help reduce soil water losses in drier conditions (Naeini and Cook, 2000; Eneji et al., 2008).
Impact on biodiversity: Positive or possibly negative – some studies have shown that the use of organic manures can increase nitrate leaching in some soils

(Beckwith et al., 1998; Basso and Ritchie, 2005) but generally organic manures are evry beneficial for soil biota.

2.6.2.13.2 Increasing rate of infiltration into soil

Mitigation measure: Diluting slurry with water, use of irrigation to after spreading manure or harrowing the soil surface increases infiltration rate into soil. This has the effect of reducing NH_3 and CH_4 emissions.
Adaptation measure: No effect.
Impact on biodiversity: Neutral to negative – there is a possible greater risk of increased surface run-off and also leaching in certain soil types (Misselbrook et al., 1995; Smith et al., 2001a).

2.6.2.13.3 Manure additives / Acidification of manure

Mitigation measure: Acidification of slurries can be an effective reducer of NH_3 volatilisation and hence emissions of NH_3.
Adaptation measure: Not applicable.
Impact on biodiversity: Probably negative – acidification of slurries and manure will in turn increase the acidification of soil which can have detrimental effects on soil and water biodiversity (Brussaard et al., 1997; van Gestel and Hoogerwerf, 2001; Mulder et al., 2003; Joschko et al., 2006).

2.6.2.13.4 Manure application techniques

Slurry application techniques
Mitigation measure: A large proportion of GHG emissions derives from application of slurries to the ground. Minimisation of these losses can be made by the use of specialist slurry placement machinery that either inject the slurry into the ground or places it directly on the surface (i.e., reducing the surface area of slurry to air and increasing infiltration). These techniques usually require large machinery which may be unsuitable for sloped land, small fields or heavy soil types.
Adaptation measure: Not applicable.
Impact on biodiversity: Neutral to negative – the use of these large machines on wet soils (e.g., spring or autumn), even with flotation tyres may cause excessive soil compaction. This will reduce the likelihood of water run-off and soil erosion which can have severe effects on biodiversity (Stoate et al., 2001); it also increase levels of soil-borne fauna (McLaughlin and Mineau, 1995).

2.6.2.13.5 Incorporation of applied manure and/or slurry into soil

Mitigation measure: When manure is spread onto arable fields (and grassland fields being re-sown or part of an arable rotation) NH_3 emissions can be reduced by ploughing or discing the manure into the soil (within four to ten hours after is best). In practice, this often occurs near human habitation to reduce the odour of manure.
Adaptation measure: Not applicable.
Impact on biodiversity: No effect.

2.6.2.14 Carbon sequestration (enhancing soil carbon)

Measures to improve carbon sequestration in agricultural soils are seen as one of the most important mitigation techniques in Europe (Vleeshouwers and Verhagen, 2002; Freibauer et al., 2004; Smith, 2004; Smith et al., 2005; Hutchinson et al., 2007; Lal, 2007b; Smith et al., 2007a). It involves techniques and measures for increasing the biomass in the soil including conversion to perennial crops, returning crop biomass to the soil and reduced cultivation techniques like no-till. Many agricultural soils have been thoroughly depleted of organic carbon content through the use of specialised practices; one figure estimates EU croplands lose 78 Mt C y^{-1} (Vleeshouwers and Verhagen, 2002).

2.6.2.14.1 Improve residue management (higher crop residue return)

Mitigation measure: Many agricultural crop and animal systems produce a lot of by-products such as straw from combinable crops, manure and slurry. Along with cover crops and green manures, the incorporation of residues and animal waste into arable crop soil can help sequester carbon. The use of green manures, animal waste products and sewage sludge will also reduce reliance on inorganic fertilisers. For crop residue though, doubt has been raised over the efficacy of incorporating it into soil as a mitigation measure when it may be more beneficial being used in power generation (Powlson et al., 2008).

Adaptation measure: Incorporating organic matter into the soil can help reduce erosion and increase the water-holding capacity of soils thereby helping farmers adapt to warmer conditions (Parry et al., 2005; Powlson et al., 2008).

Impact on biodiversity: Positive and negative – There are many things to consider when discussing the possible outcomes for biodiversity when incorporating organic matter into the soil: type of residue, soil type, timing, incorporation method. Generally speaking, the addition of organic matter to soils, especially depleted soils, will be beneficial for soil fauna and soil functioning (structure, water retention, nutrient cycling) (Stinner and House, 1990; Stoate et al., 2001; Joschko et al., 2006; Powlson et al., 2008); however, these effects are not uniform.

One example of a possible negative effect results from the direct incorporation of cereal straw into the soil:

- Straw incorporation can increase nitrogen needs for the following crop due to nitrogen immobilization associated with residue decomposition (and possibly soil denitrification and residue phytotoxicity) which will result in additional fertiliser applications for the following crop (Moraghan et al., 2003).
- Straw in the seedbed can also increase soil pest numbers (e.g., slugs) which will result in the additional use of pesticides (Hunter, 1967; Glen et al., 1989; Symondson et al., 1996) although this varies with incorporation technique (e.g., plough vs. tines) (Turley et al., 2003).
- Nitrate leaching may also increase (Beaudoin et al., 2005).

Other negative effects may occur: Basso and Ritchie (2005) found the nitrate leaching levels were highest in a maize/lucerne rotation with manure applications followed by compost and then inorganic fertiliser.

2.6.2.14.2 Land-use change

Four main land-use conversions from arable cropping are considered here: grassland, agroforestry and woodland; conversion of grasslands to silvopasture or woodlands is also discussed (see also section 3).

Mitigation measure: The conversion of arable land to forested or permanent grassland or the extensification of arable land by introducing perennial crops (e.g., agroforestry) increases the carbon sequestration potential of the land. Increase in biomass in the soil is achieved by permanent rooting systems; biomass above–ground is considerably enhanced also, particularly in agroforestry and forestry conversion (Vesterdal et al., 2002).

Adaptation measure: Climate change may force some farmers to abandon arable production in favour of a grassland or afforestation. In the tropics, agroforestry is used extensively to control microclimate and provide nutrients for annual and perennial crops (e.g., Lin, 2007; Verchot et al., 2007), but these principles can also be applied in Europe (Von Maydell, 1995; Palma et al., 2007a; Palma et al., 2007b).

Impact on biodiversity: Mostly positive – With the exception of taking wildlife-friendly arable systems out of production (e.g., croplands with high 'ecosystem value' are mainly found in Mediterranean and Scandinavian countries and Austria: Franco and Sutherland, 2004; Reidsma et al., 2006). Most land-use change involving increasing grassland, woodland or agroforestry systems would be beneficial for biodiversity. The improvements in biodiversity will mainly be related to increasing landscape heterogeneity (Benton et al., 2003; Vickery et al., 2004) as well as reducing the intensity of agricultural production (Wilson et al., 1999; Stoate et al., 2001; Robinson and Sutherland, 2002; Reidsma et al., 2006); although success of some agri-environment schemes designed to reverse agricultural intensification has proven to be difficult to quantify (Kleijn and Sutherland, 2003; Primdahl et al., 2003; Kleijn et al., 2006). Indeed, many of theses land-use changes may require decades to come close to the levels of biodiversity of original semi-natural habitats and even then success is far greater when new habitats are created next to existing ones due to ease of species dispersal (Grashof-Bokdam and Geertsema, 1998; Harmer et al., 2001; Bellemare et al., 2002; Wulf, 2004; Brunet, 2007).

There is enough evidence to suggest that conversion from most arable land-use will be beneficial to biodiversity: relative success has been achieved in converting arable to grassland (Pywell et al., 2002), to woodland (Santos et al., 2006) and agroforestry (Burgess, 1999; Klaa et al., 2005). In homogenous landscapes any addition of a semi-natural habitat will generally prove beneficial (Duelli and Obrist, 2003; Bennett et al., 2004); however, design and location is important in most landscapes and careful positioning of land-use conversion will be required to achieve full biodiversity potential (Van Der Horst and Gimona, 2005).

Extensification through agroforestry schemes is likely to be beneficial for biodiversity (Eichhorn et al., 2006; Cowie et al., 2007), through soil improvement, erosion control and reducing nitrate leaching (Palma et al., 2007b; Verchot et al., 2007), but also by providing habitat for pest predators thereby reducing the need for pesticides (Jordan, 2004) (although the reverse can be true also, e.g., slugs can be a problem (Griffiths et al., 1998)). Provision of habitat for other taxa is one major benefit of agroforestry schemes (Klaa et al., 2005), although care has to be taken to ensure that major alterations of the landscape will not affect important taxa (Franco and Sutherland, 2004).

Conversion to woodland can benefit the environment in many ways: from improving water quality (and river biodiversity) (Bastrup-Birk and Gundersen, 2004; Van Der Salm et al., 2006; Hansen et al., 2007) to stabilising soil (Lopez-Moreno et al., 2006) and providing habitats to a range of taxa (Harmer et al., 2001; Wulf, 2004; Van Der Horst and Gimona, 2005; Santos et al., 2006).

Forests can have a major impact on the water balance at the local scale (Andréassian, 2004); forests generally have higher evapotranspiration rates than other types of vegetation (and particularly arable rotations) which can have positive and negative effects for biodiversity. The impact of afforestation will depend upon soil type and geology, climatic conditions and the choice of species planted (Andréassian, 2004; Farley et al., 2005). For example, whilst forest cover can have major positive effects on flood volumes and peaks (Cosandey et al., 2005; Lopez-Moreno et al., 2006; Bradshaw et al., 2007) there is still major uncertainty in their role in flood alleviation (Andréassian, 2004; Calder and Aylward, 2006; Calder, 2007). Afforestation schemes can affect the ground water characteristics at even a comparatively young age; for example, Van Der Salm et al., (2006) showed that ground water recharge decreased from 485 mm/yr on arable to land to 172 mm on an 18 year oak plantation. Changes in groundwater recharge brought on by afforestation may affect stream flow volumes (Farley et al., 2005; Jackson et al., 2005; Wattenbach et al., 2007) with possibly negative consequences for biodiversity.

Caution must be urged when choosing species for afforestation projects, particularly non-native species (Peterken, 2001; Carnus et al., 2006); for example, the use of Eucalyptus spp. in Portugal can have major effects on water flow as well as biodiversity (resulting from toxic leaf leachates) in streams (Canhoto and Laranjeira, 2007).

The outcome for biodiversity from grassland conversions to agroforestry (i.e., silvopasture) or woodlands will, like conversion from arable land, depend upon the biodiversity value of the original grassland. An intensively managed monoculture of Lolium perenne for example, will almost certainly gain from planting trees for silvopasture or woodland whereas a species-rich chalk grassland will undoubtedly suffer a reduction of biodiversity. At the same time, in some parts of Europe, silvopasture systems are often some of the most diverse and unique habitats, e.g., the dehesas in Spain (Plieninger and Wilbrand, 2001; Robles et al., 2007; Tárrega et al., 2007), the montado in Portugal, wood-pastures in England, France and Switzerland (Kirby et al., 1995; Rackham, 2003; Sjögren, 2006) and Streuobst in central Europe (Herzog, 1998).

Restoration or recreation of a silvopasture system will not be able to match any of the traditional systems above for biodiversity but they can still improve biodiversity in grasslands by providing new habitats (McAdam et al., 2007), reduce leaching and improve fertility (and hence reduce fertiliser inputs) (Teklehaimanot and Mmolotsi, 2007). As for afforestation schemes on arable lands, planting of trees in water sensitive areas may result in reduced stream flow and a reduction in aquatic biodiversity.

2.6.2.14.3 Reduced tillage and no-tillage

This has been covered in section 2.6.2.4

2.6.2.14.4 Promotion of permanently shallow water table in farmed peat land

Mitigation measure: Groundwater levels nearer to the soil surface in peat lands (<30cm) maintain anaerobic conditions, which as well as inhibiting N_2O production will also help to maintain carbon levels in the peat (Best and Jacobs, 1997; Lloyd, 2006).
Adaptation measure: Maintaining shallow water tables will help peat bogs sustain their vitally important ecosystem services (flood and erosion control, water supply, pollution filtration, nutrient recycling) (Kracauer Hartig et al., 1997). Climate change may threaten peat lands by altering hydrological regimes.
Impact on biodiversity: Positive - many temperate climate peat lands are not the most diverse in terms of species richness but they do maintain unique species and are valued highly for by conservationists (Moore, 2002). Efforts in restoration of peat lands have proved worthwhile for a number of species (Van Duinen et al., 2003; Malson and Rydin, 2007).

2.6.2.14.5 Reduced bare fallow frequency/Elimination of bare fallow

Mitigation measure: Bare fallow increases the risk of erosion of soil, which can lead to carbon losses to the atmosphere; the lack of vegetation in a fallow also results in no carbon input to the soil. Catch crops during the winter period is one possible option, also permanent revegetation on set-aside land.
Adaptation measure: Climate change may exacerbate the risk of soil erosion on fallow land (from floods or from droughts), as well as improve water infiltration rates in soil thereby reducing flood effects.
Impact on biodiversity: Positive or negative – the adoption of either spring or winter sown crops could have beneficial effects depending upon location and the addition of other management prescriptions. In western Europe, one of the main reason for agri-biodiversity loss has been the decline in spring cropping

systems (Benton et al., 2003; 2006), because of the weed habitats that invertebrates and ground-nesting birds require (Hald, 1999; Moorcroft et al., 2002; Bengtsson et al., 2005; Fuller et al., 2005; Hole et al., 2005). However, catch crops can provide habitat and food sources for invertebrates, mammals and birds (Stoate et al., 2003) as well as help reduce run-off and nitrate leaching (Beckwith et al., 1998; Sharpley et al., 2000; Macdonald et al., 2005).

2.6.2.14.6 Cultivation of energy crops

Mitigation measure: The adoption of perennial bioenergy crops like short-rotation coppice, and some grass species has potential for carbon sequestration in the soil
Adaptation measure: Can enhance and maintain soil structure and functioning which will help adapt to future climate change events like floods and drought (Christian et al., 1994; Ranney and Mann, 1994; Börjesson, 1999).
Impact on biodiversity: See below in section 2.6.2.15.

2.6.2.15 Bioenergy crop production

In recent years there has been a proliferation of studies advocating bioenergy schemes for climate change mitigation. As a consequence, in the EU-25, an estimated 3.6 million hectares of agricultural land were used for biomass production in 2005 (European Environment Agency, 2007). The range of biomass crops and production processes is quite varied although the end use for the energy is normally only for heat production, electricity or transport fuel. Perennial bioenergy crops can potentially be a major boon to carbon sequestration in Europe but they are, along with annual crops, also deemed worthwhile as a fossil fuel substitute. There remains an ongoing debate as to whether the production of some bioenergy crops is actually a positive mitigation measure when one considers the energy required for production, transport and processing as well as externalities like crop displacement (Giampietro and Ulgiati, 2005; Laurance, 2007; Zah et al., 2007; Fargione et al., 2008; Searchinger et al., 2008).

Here we just assess the affects of bioenergy production on biodiversity regardless of their mitigation worth. Rather than assess bioenergy crop production grouped by conversion process (e.g., combustion, anaerobic digestion, fermentation, inter-estification, etc), we assess the on-farm production of each type of biomass feedstock (i.e., the product being grown) as most of the environmental impacts can be ascribed to this portion of the biofuel production cycle (Zah et al., 2007)

We have considered the predominant crop types grown in Europe (e.g., Brassica napus) as well as some possible developments in the future (e.g., genetically modified crops); issues of land-use change and leakage (displacement of food crops) are also discussed.

2.6.2.15.1 Short-rotation coppice

Short-rotation coppice (SRC) in Europe usually involves the cultivation of *Salix*, *Populus*, *Robinia* and *Eucalyptus* species planted in straight rows (to allow mechanised harvesting) and harvested in three to five year rotations (Mitchell et al., 1999). The harvested product is used normally in combustion for heat or electricity generation, but can be processed to produce ethanol too (Krotscheck et al., 2000; Sims et al., 2006; Simpson et al., 2008).
Adaptation measure: SRC has great potential for climate change adaptation in agricultural systems. Like afforestation projects, it can enhance and maintain soil structure and functioning which will help cope with events like floods and drought (Christian et al., 1994; Ranney and Mann, 1994; Börjesson, 1999).
Impact on biodiversity: Positive and negative – the adoption of SRC has been touted as a boon to biodiversity by creating habitats for a range of taxa but particularly birds (Berg, 2002) and insects (Reddersen, 2001). Plant diversity is not usually very high in SRC mainly because of the use of herbicides to control weeds – this has direct negative consequences for small mammals also as they require an herb layer for cover (Sage, 1998). SRC has other benefits too though: it can be a valuable tool for improving soil structure and function (Lemus and Lal, 2005; Powlson et al., 2005; Boehmel et al., 2008); as well as the ability of SRC to reduce nutrient loss to the atmosphere and water courses and pesticide pollution of soils and water (Makeschin, 1994; Ranney and Mann, 1994; Borjesson, 1999; European Environment Agency, 2007; Goodlass et al., 2007). SRC also requires fewer inorganic fertiliser inputs (Boehmel et al., 2008).

On the negative side there are concerns over water use demands of SRC (Calder, 2007), particularly where they are adopted in water-stressed environments (Berndes, 2002; Farley et al., 2005; Berndes, 2008). Additional problems can result from harvesting, which commonly takes place during the winter months using large specialised machines (Mitchell et al., 1999): in the wetter soils the risk of soil compaction is compounded (Souch et al., 2004), which can lead to the associated problems like increased surface run-off etc (Stoate et al., 2001; Zalidis et al., 2002; Hamza and Anderson, 2005).

2.6.2.15.2 Herbaceous crops (grasses)

The use of four main grass species for bioenergy production include Miscanthus (*Miscanthus* spp.), Giant Reed (*Arundo donax*) , Switchgrass (*Panicium virgatum*) and Reed Canary grass (*Phalaris arundinacea*) (Scholz and Ellerbrock, 2002; Lewandowski et al., 2003; Heaton et al., 2004; Powlson et al., 2005; European Environment Agency, 2007)
Adaptation measure: The use of these tall grasses in agricultural systems may provide benefits in terms of improving soil structure and function, which would reduce run-off and erosion risk in floods; also, they would potentially provide shade for neighbouring livestock in hot conditions (European Environment Agency, 2007)
Impact on biodiversity: Positive or negative – grassland ecosystems are usually

more biodiversity friendly than arable food crop rotations (certainly in terms of reducing indirect threats to biodiversity like erosion, run-off, leaching, pesticide usage and can be used as buffer strips) as well as other energy cropping like maize (Lewandowski et al., 2003; Heaton et al., 2004; Parrish and Fike, 2005; European Environment Agency, 2007; Boehmel et al., 2008). It can also provide a more disturbance-free environment for wildlife too (Giuliano and Daves, 2002; Semere and Slater, 2007b; Semere and Slater, 2007a); however, there is still a fair amount of uncertainty as to how much wildlife would find tall grass monocultures suitable habitat.

Research in the US has shown that the use of diverse native perennial grasslands may be a viable alternative to monocultures of grass species particularly as they can be sown on abandoned or degraded land (Tilman et al., 2006). This approach would have other benefits as it would not require large amounts of inputs either (Tilman describes it as 'Low-Input-High Diversity' grassland or LIHD); however, there are concerns that the adoption of LIHD may result in marginal lands in Europe currently used for grazing land being used for biofuels (Ceotto, 2008). This could have dramatic effects on biodiversity if it displaces grazing land to other conservation habitats elsewhere or results in a degraded habitat due to lack of grazing (Dullinger et al., 2003; Luoto et al., 2003; Cremene et al., 2005; Pykälä et al., 2005; Baur et al., 2006).

A further problem with the adoption of grass species for bioenergy production is the risk of some species becoming invasive (Raghu et al., 2006; Barney and DiTomaso, 2008). The four species listed above have all been shown to have invasive traits (Raghu et al., 2006) and can result in reduced biodiversity and increased fire hazard (Herrera and Dudley, 2003; Schooler et al., 2006; European Environment Agency, 2007).

2.6.2.15.3 Crop residues (straw, etc)

Agricultural by-products like crop residues can be used for bioenergy production (Kim and Dale, 2004; Somerville, 2006; Ceotto, 2008). All crops produce a by-product (e.g., straw from cereals, haulm from peas, beans and potatoes, etc), which is easily converted to an energy source in the same way as any other ligno-cellulose material.

Adaptation measure: Not applicable

Impact on biodiversity: Negative - the resulting loss of crop residues biomass from the soil results in reduced field fertility (Karlen et al., 1984; Varvel et al., 2008), which will require more nitrogen fertiliser inputs for the following crop. Even crop residues used for livestock (e.g., straw for bedding or feed) is usually returned to the field as manure. Furthermore, the reduced levels of organic matter content in the soil will have negative implications for soil erosion, water run-off etc (Lal, 2005; Lal and Pimentel, 2007).

2.6.2.15.4 Sugar and starch crops

Potatoes, maize and sugar beet can be converted to ethanol through fermentation (Sims et al., 2006).

Adaptation measure: Not applicable
Impact on biodiversity: Neutral to negative – The impacts of growing intensive annual crops have been discussed elsewhere in this report; these two crop species are no different from any other annual crop grown intensively – they both require large amounts of fertiliser and pesticide inputs and irrigation is often used to achieve respectable yields (European Environment Agency, 2007). Furthermore, the drilling/planting and harvesting seasons (spring and autumn) for these crops increases the risk of erosion from working on bare soils (Hamza and Anderson, 2005); compounding this is the fact that harvesting is often done with large machines (some weigh over 20 tonnes), which in wet conditions can result in increased soil degradation (Schafer-Landefeld et al., 2004; Tzilivakis et al., 2005). In general, these energy crops are some of the most environmentally degrading – the overall impact stemming from heavy machinery, timing of operations, water use, fertiliser use, pesticide use can have severe consequences for soil degradation leading to erosion, run-off, leaching etc (Pimentel, 2003; Hill et al., 2006; Simpson et al., 2008).

2.6.2.15.5 Oil and cereal crops

Oil crops (mustard, rape, sunflower, linseed) and grain crops (wheat barley, oats, rye) can be grown in a normal arable crop rotation to produce biofuel in the form of biodiesel esters (oil crops) and ethanol (grain crops) (Sims et al., 2006).
Adaptation measure: Not applicable
Impact on biodiversity: Positive to negative – in most respects cereal and oilseed crop production would have a lower impact than the sugar and starch crops (European Environment Agency, 2007), although would not be as benign as short-rotation coppice (Boehmel et al., 2008). Otherwise, production of oil and cereal crops in a biodiversity-friendly manner such as an organic farming (Swanston and Newton, 2005; Fredriksson et al., 2006; Hansson et al., 2007), or no-till (Boehmel et al., 2008), can reduce their ecological impact considerably.

2.6.2.15.6 GM breeding

The use of crop breeding and genetic modification in breeding to increase productivity in bioenergy crops is a major goal in research (Ragauskas et al., 2006; Groover, 2007). For example, tree genomic research can focus on identifying the genes responsible for traits relating to increasing carbon partitioning to above-ground woody matter as well as the traits which would increase cellulose availability for enzymatic digestion (Groover, 2007). Other improvements for improving biomass crops include manipulating the genes responsible for nitrogen metabolism, delaying senescence and dormancy, and increasing photosynthesis (Ragauskas et al., 2006).
Adaptation measure: Genomics has the potential to improve drought tolerance, flood tolerance (Dennis et al., 2000), pest and disease resistance and tolerance of saline soils (Ragauskas et al., 2006; Groover, 2007).
Impact on biodiversity: Positive and negative – improving the yield of bioenergy crops could result in less land being required for production (and hence a lower likelihood of conservation land being used) (Koh, 2007). Also, species that are

better able to utilise inorganic inputs would result in a lower impact on the environment; however, there are concerns over GM breeding in bioenergy crops (for those existing arable crops used for bioenergy - see section 2.6.2.10); Firbank (2008) highlights concerns over the potential for gene transfer to wild relatives (particularly in areas with high genetic diversity) but there are also concerns about their invasiveness potential (Hoenicka and Fladung, 2006).

2.6.2.15.7 Land-use change

An increase in bioenergy production in Europe will result in major changes in land-use, not only because different crops will be used on agricultural land, but also because other land-use types may be converted (e.g., semi-natural grasslands, degraded lands). Conflict over land-use between bioenergy and food production are particularly highlighted in many papers (see Mattison and Norris, 2007; Fargione et al., 2008; Field et al., 2008 and references therein) and the consensus is that more land will be required in the future to meet global bioenergy production demands (Righelato and Spracklen, 2007). This may not have a major deleterious effect on European biodiversity if the area of land for food production declines (Rounsevell et al., 2005); however, if the food crop area is maintained and bioenergy crop production increases to meet EU demand then the likelihood of using marginal land will increase also with the potential for major ecological disruption.

The implications of increased bioenergy production on a landscape scale can be positive or negative: much will depend on local circumstances, habitats may be degraded or conversely they could be created (Firbank, 2008). In homogenous landscapes with low biodiversity value increasing the heterogeneity will have positive effects for biodiversity (Benton et al., 2003); conversely, the conversion of semi-natural habitats to bioenergy would likely have the opposite effect (Koh, 2007; Groom et al., 2008; Firbank, 2008).

2.6.2.15.8 Displacement of food crops (indirect effects)

Linked to land-use change is the burgeoning issue of ‘leakage’ (food crop displacement) that the rush to adopt bioenergy production may effect (Gregory et al., 2005; Cassman, 2007; Naylor et al., 2007; Schmidhuber and Tubiello, 2007; Field et al., 2008; Searchinger et al., 2008). Food crop displacement has already resulted in further deforestation in the Amazon and conversion of tropical savannas as a result of US farmers switching fields from soybean production to maize (corn) for biofuels (Laurance, 2007; Scharlemann and Laurance, 2008). The rise in global (and European) food prices is due to a number of factors but the switch to biofuel production by European and world farmers is certainly one of them (Sheeran, 2008). One of the consequences of this will be further degradation of natural habitats for conversion into food production (Lewandowski and Faaij, 2006; Searchinger et al., 2008).

2.6.2.15.9 Multi-crop comparisons

Comparing the environmental impact of different crops has an established history in the scientific (Scholz and Ellerbrock, 2002; Powlson et al., 2005; Hill et al., 2006; Boehmel et al., 2008; Groom et al., 2008) and grey literature (European Environment Agency, 2007; Zah et al., 2007). General patterns do emerge from these analyses:

- Wood-based or native prairie-grass biomass production is the most biodiversity-friendly.
- Annual crops, in particular potatoes, maize and oilseed rape are the worst for soil degradation, chemical inputs and biodiversity.

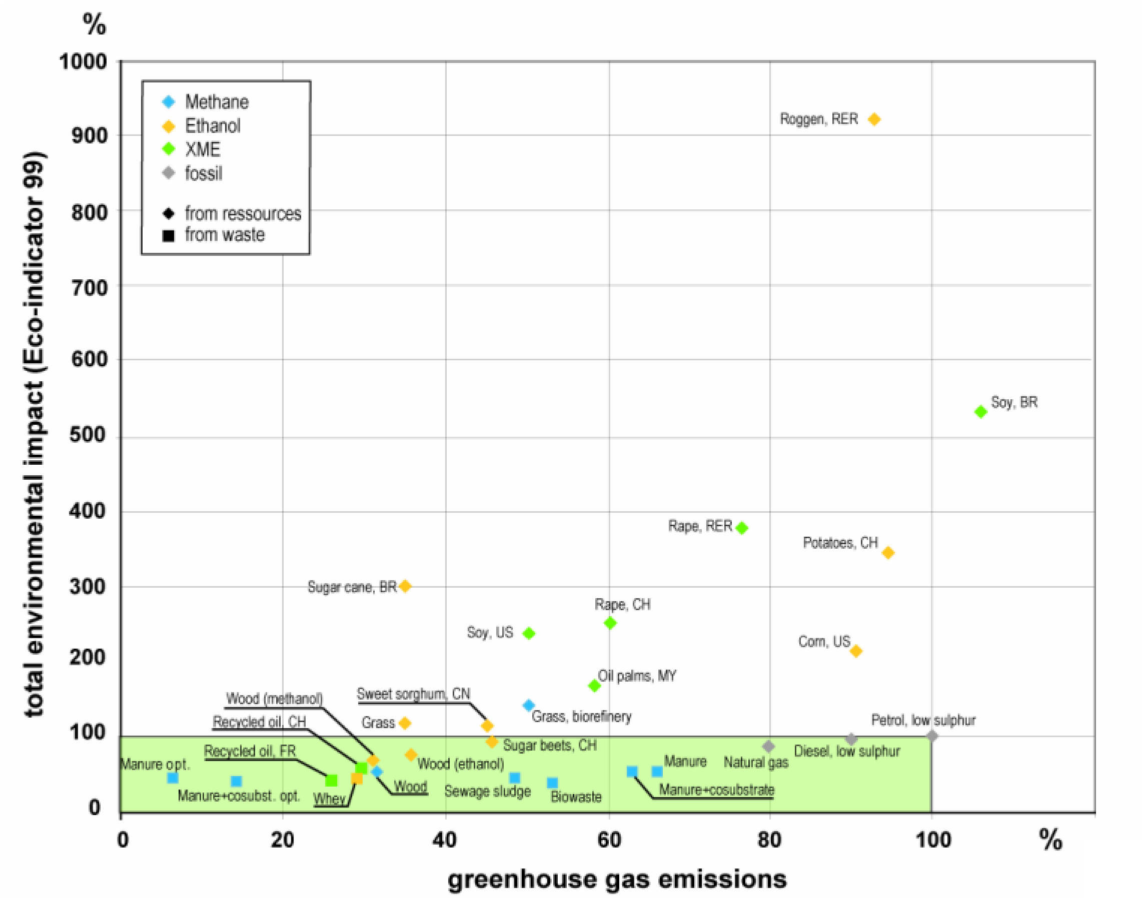


Figure 2.2: Environmental Impact and GHG emissions from 29 transport fuels (gasoline is the reference fuel) – European Union fuels are marked EU. The green shading indicates a lower environmental impact and GHG emission than gasoline. Source: from a translation of Zah et al (2007) by Scharlemann and Laurance (2008)

Perhaps the most comprehensive report yet is by Zah et al (2007) who looked at the environmental impacts of twenty-six different biofuel crops using an "ecological life-cycle analysis" (they use two different approaches that mainly encompassed human health impacts as well as ecosystem impacts - ecotoxicity, land use impact, eutrophication and acidification). They came to a number of conclusions:

- Agricultural cultivation of the biofuel crop accounted for most of the environmental impact.
- There is a trade-off between minimising GHG emissions and reducing

ecological impact - most of the biofuels that reduced GHGs by more than 30% have a higher ecological impact than petrol (all biofuels were compared to the ecological and GHG effects of petrol).
- In European countries, it is the use of fertilisers and cultivation of the soil that had the biggest ecological impact however these impacts can be lessened with different management measures.

Figure 2.2 highlights the range of GHG and environmental effect of the crops studied.

2.6.2.16 Tillage, planting and harvesting timing changes

Mitigation measure: The increased incidence of wetter winters and floods will undoubtedly affect the timing of many farming operations (e.g., drilling, spraying, harvesting). The ability of a farmer to cope with these changes (e.g., using tracked-laying vehicles or flotation tyres vehicles to reduce compaction in wet conditions) will go a long way to improving crop yield and hence productivity.
Adaptation measure: Farmers may have to adapt to changes in crop phenology or climatic events like wetter winters and autumns (prohibiting access to water-logged soils). This may result in changes in machinery to cope with conditions, changes in crop rotation (e.g., possible switch from spring-sown crops to autumn-sown crops) or drilling/cultivating/harvesting at sub-optimal times (Tubiello et al., 2000); however, wetter winters may prohibit the use of winter sown crops due to anaerobic conditions.
Impact on biodiversity: Positive of negative – farmers persistently operating on wet soils will degrade them (Hamza and Anderson, 2005); reducing ground pressure with flotation tyres or tracks will go some way to preventing these problems although there is a limit to their utility in extremely wet soils. Changes in crop rotation may have positive or negative effects.

2.6.2.17 Change in herbicide and pesticide usage

Mitigation measure: Climate change may result in a greater or lesser abundance and diversity of weed, pathogen and pest species (Easterling and Tubiello, 2007). New species may start to appear (Scherm, 2004; Davies et al., 2007; Duveiller et al., 2007) and farmers may have to use more pesticides to maintain crop yield and productivity. Some pest numbers may decrease though (e.g., aphids in southern England: Newman, 2005).
Adaptation measure: As above
Impact on biodiversity: Positive or negative – Increased use of herbicides and pesticides will reduce weed diversity and abundance which will also affect water quality, invertebrate numbers etc. Conversely, reductions in chemical inputs will be beneficial for biodiversity (McLaughlin and Mineau, 1995; Stoate et al., 2001; Brooks et al., 2005). Impacts are likely to be regional.

2.6.3 Farm-scale management options

2.6.3.1 Integration of plant and animal production

Mitigation measure: Integrating plant and animal production reduces the need of external inputs (e.g., nutrients, livestock feed). This is commonly practiced in many EU farms already but has declined over the last few decades as farms have become more specialised (Stoate et al., 2001).
Adaptation measure: Reducing specialisation will increase the farm's 'insurance' against climate change related disaster, i.e., a more heterogeneous crop and livestock system will be more resilient to climate change
Impact on biodiversity: Positive – there is a limit to how far integration can occur (e.g., arable cropping would be impossible in montane farms) and some 'non-integrated' systems may be very biodiversity-friendly already, but generally the addition of another farm system is likely to increase landscape heterogeneity in most farmland areas which will have beneficial effects for biodiversity (Benton, 2007).

2.6.3.2 Extensification/Intensification and livestock density

Mitigation measure: Both extensification and intensification have been cited as possible methods of climate change mitigation: intensification by improving productivity per unit area; extensification as the exact opposite. Most studies (see references in Weiske, 2005) have shown that extensification reduces GHG emissions for cattle, pigs and sheep systems; however, it has been shown that high milk production in dairy cows emits lower CH_4 per litre of milk.
Adaptation measure: Extensification may be forced upon farmers due to lower carrying capacity of grasslands in drier summers.
Impact on biodiversity: Extensification – positive; intensification – negative. The pattern of agricultural intensification in Europe over the last century has had well-documented consequences for biodiversity (McLaughlin and Mineau, 1995; Stoate et al., 2001; Robinson and Sutherland, 2002) – a move towards extensification will improve the environmental impact at the farm-scale and local landscape scale (Green, 1990; Line et al., 2000; Wolff et al., 2001); however, this may result in other marginal land be converted to agriculture to make-up any yield shortfalls elsewhere.

2.6.3.3 Increase of grazing in comparison to animal housing

Mitigation measure: NH_3 emissions are lower per animal for grazing animals than for housed animals.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive to negative – grassland management for grazing animals can have negative impacts (see section 2.6.1.3); however, if intensively-farmed arable land is converted to grazing land it will reduce the environmental impact.

2.6.3.4 Increase of the grassland ratio in relation to arable land

Mitigation measure: Grassland is a better store of soil carbon than arable land due to perennial plant growth and less soil disturbance.
Adaptation measure: Grassland will offer more resilience to climate change events like floods and drought.
Impact on biodiversity: Positive – under most arable landscapes the addition of grassland patches will be beneficial for biodiversity: soil erosion, leaching, run-off will all be reduced; grassland will also increase the landscape heterogeneity (Benton et al., 2003).

2.6.3.5 Switch to Organic farming

Mitigation measure: Organic farming has been promoted as a measure to help increase carbon mitigation in arable farms mainly by increasing soil organic matter, extensification and manure use (Pimentel, 2003; Freibauer et al., 2004; Leifeld and Fuhrer, 2005; Borron, 2006; Johnson et al., 2007).
Adaptation measure: There is potential for organic farming to offer better adaptation capacity than conventional farming: improved soil structure and functioning is a main tenet of organic farming, which will increase the ability of the soil to cope with warmer summers (better moisture retention) and also climate change events like floods and drought (Wall and Smit, 2005; Borron, 2006; FAO, 2007). A greater diversity of crops produced (e.g., legumes in crop rotation) also reduces the risk of losing an entire year's production if one crop suffers (Wall and Smit, 2005).
Impact on biodiversity: Positive – there is a burgeoning literature assessing the effects of organic agriculture on biodiversity and although some reports are not consistent in their conclusions (mainly highlighting methodological issues); generally biodiversity is higher at the farm scale (O'Riordan and Cobb, 2001; Hyvönen et al., 2003; Crews and Peoples, 2004; Bengtsson et al., 2005; Fuller et al., 2005; Hole et al., 2005; Clough et al., 2007; Hyvönen, 2007; Holzschuh et al., 2008); however, the loss of productivity in organic systems may result in a greater intensification or land-use change elsewhere to compensate (Green et al., 2005).

2.6.3.6 Abandon crop and livestock production

Mitigation measure: A highly controversial measure would be a large-scale reduction of livestock production (Steinfeld et al., 2006; Baroni et al., 2007; McMichael et al., 2007) either through extensification (see section 2.6.3.2) or complete abandonment. As well as emitting high levels of GHGs, livestock require more water, land and energy to produce the same amount of protein as a crop-based diet for human consumption (Smil, 2002; Pimentel and Pimentel, 2003; Baroni et al., 2007). Crop abandonment could be applied as a mitigation strategy by replacing annual plant crops with perennial vegetation cover (grasses for conservation of biofuels, afforestation). Abandonment may go hand-in-hand with an increased concentration of productivity in other areas to compensate for the loss of production (Green et al., 2005; Matson and Vitousek, 2006)

Adaptation measure: Crop and/or livestock abandonment may be forced onto some farmers if climatic conditions become too extreme (Berry et al., 2006). Abandonment may improve adaptive capacity at the landscape scale though – increased vegetation cover (from afforestation or weed and grass invasion) will improve soil structure and function and reduce the risk of flood damage (Fischer et al., 2006; Lopez-Moreno et al., 2006).

Impact on biodiversity: Positive and negative – the abandonment of biodiversity-friendly agricultural areas would result in an overall loss of biodiversity (Reidsma et al., 2006; Henle et al., 2008). For example, abandonment of species-rich hay meadows would result in the eventual loss of biodiversity associated with scrub and forest succession into grasslands; this is a risk in lowland and steppe grasslands (Franco and Sutherland, 2004; Cremene et al., 2005; Pykälä et al., 2005) and sub-alpine meadows (MacDonald et al., 2000; Dolek and Geyer, 2002; Dullinger et al., 2003; Baur et al., 2006). Other cropping types in Mediterranean regions have also suffered a loss of biodiversity due to abandonment (Tella and Forero, 2000; Moreira et al., 2001; Sirami et al., 2008). A reduction in landscape biodiversity has also been reported (Luoto et al., 2003).

To counter that argument, the partial abandonment of agricultural land has been shown to improve biodiversity; for example, the long-standing use of set-aside in parts of Europe has, in places, fostered high levels of plant, insect, mammal and bird diversity (Sotherton, 1998; Buckingham et al., 1999; Moorcroft et al., 2002; Bradbury et al., 2004; Falloon et al., 2004; Henderson et al., 2004; Vickery et al., 2004; Bracken and Bolger, 2006; MacDonald et al., 2007; Orłowskia and Czarnecka, 2007). In parts of Spain, abandonment is important for the conservation of steppe specialist species like Dupont's Lark (Laiolo and Tella, 2006). Also, although the abandonment of improved grassland is unlikely, increased species and structural diversity would follow.

2.6.3.7 Microclimate manipulation

Mitigation measure: Warmer, drier summers may result in reduced yields of some crop species; the use of microclimate manipulation techniques like shade screens and tunnels is common in horticulture but could be adapted for high-value agricultural crops or livestock. Alternatives include using only north-facing aspects in hilly areas, intercropping with trees, small woodlots (e.g., for pigs), and use of fabric shading.

Adaptation measure: As above, the use of microclimatic manipulation may be necessary for some crop and livestock species.

Impact on biodiversity: Neutral to positive – while the addition of poly-tunnels or fabric shade netting may not confer any biodiversity advantage it is unlikely to be adopted on a large scale due to the high costs involved. The use of trees for shade either in shelter belts, intercropping or small woodlots would likely be better for biodiversity in most regions by increasing landscape heterogeneity (Benton et al., 2003). In hilly regions, farmers may be forced to move production away from southern slopes to northern slopes (colder and wetter); this may affect current forested or semi-natural grassland on northern slopes.

2.7 Conclusion

It is apparent from the review that climate change mitigation and adaptation measures vary considerably in their impact on biodiversity, but also even a single measure can result in different impacts depending on location, soil type, management, current biodiversity, etc. The difficulty with this will be disseminating this variance in impact to the practitioner – what may be good for one farmer may not for another. Figure 2.3 provides a summarised overview of the interactions between mitigation, adaptation and biodiversity in various agricultural management measures.

For example, the use of winter cover crops to mitigate GHG may well provide excellent habitat and feed opportunities for insects, small mammals and birds; however, if the farm has populations of ground-nesting or granivorous birds (e.g., stone curlews, seed-eating passerines, cirl buntings, grey partridge, yellowhammer, corn buntings, skylark, lapwings) that rely upon over-winter stubbles this may be negated. In parts of northern Europe where agri-environment schemes have been introduced to help conserve rare birds in this situation (e.g., stone curlew in parts of England) – care must be taken that pan-European prescriptions for climate change measures do not counter the potential good conservation work that has already been achieved (or will counter future opportunities).

This raises an interesting issue of how current and future top-down intervention in agricultural and conservation policy (agri-environment schemes, NVZs, taxes, quotas, subsidies, etc) will affect conservation if their main emphasis becomes climate change mitigation or adaptation. Of course, in an ideal world we would seek the perfect combination of 'win-win-win' where mitigation, adaptation and biodiversity conservation are all achieved (and we could add other wins for farm profitability, sufficient food supply etc) (Klein et al., 2007); however, in practice this may be difficult to achieve with many of the measures outlined above.

Perhaps though for each measure considered we should enforce the consideration of a few simple questions (adapted from: Firbank, 2008):

- Does the proposal threaten, or buffer, existing high quality habitats in the landscape?
- Does the proposal affect landscape diversity, structure and turnover?
- For new crop species, is it likely to prove invasive in its new environment?
- Is there potential for species losses or gains through landscape modification?

After doing this we may still find that the need for a particular measure overrides the conservation of the particular species/habitat/landscape in question. Sacrifices may well have to be made, which will entail careful and thorough justification; this will raise issues of how we value and understand biodiversity (e.g., is conserving a rare endemic more important than a large habitat which provides more in terms of ecosystem services?).

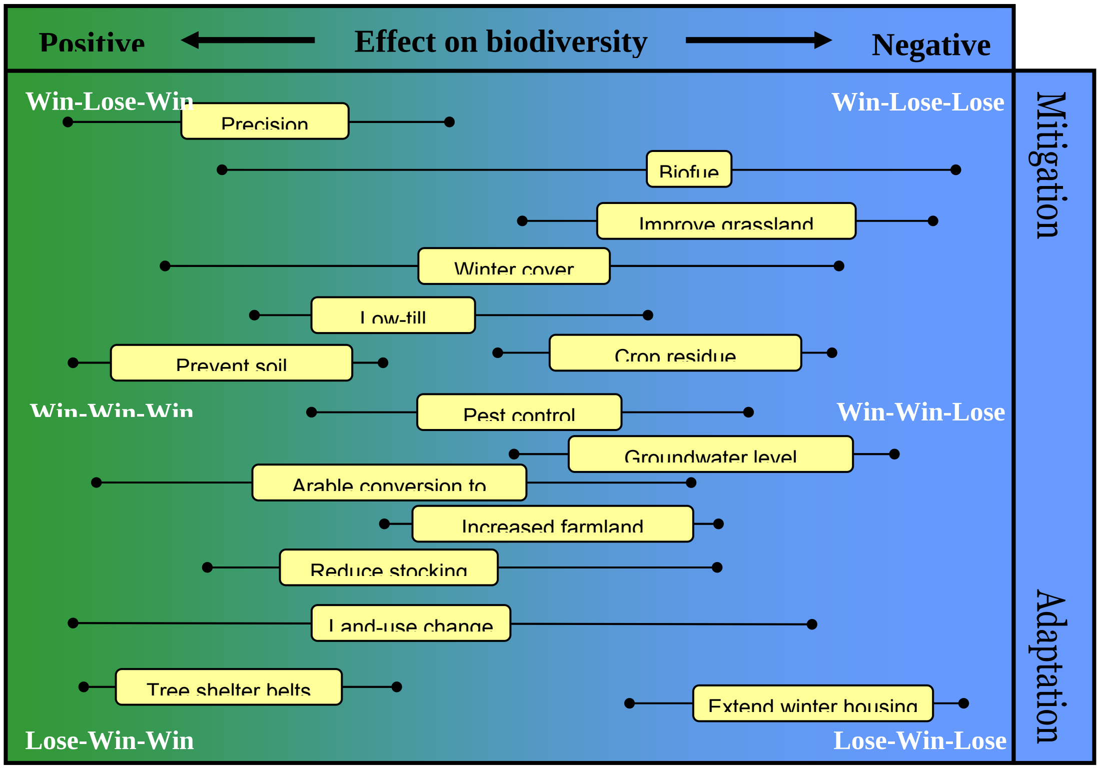


Figure 2.3: Known and potential relationships between mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on a literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts.

2.7.1 Biodiversity Impact Table

The table below summarise the impact of each measure on biodiversity. It identifies the worst-case management scenario (e.g., a careless and inconsiderate adoption of a measure) and the best-case (e.g., following Good Practice); it also identifies the habitats and taxa affected. The arrows indicate the degree of impact:

- ↑ Highly beneficial for biodiversity,
- ↗ Moderately beneficial for biodiversity,
- ↔ No known effect on biodiversity,
- ↘ Moderately detrimental for biodiversity,
- ↓ Highly detrimental for biodiversity,
- ? Indicates uncertainty over outcome due to lack of reliable data.

Livestock & Poultry Mitigation or Adaptation Strategy			Habitats affected									Taxa affected						
	Impact under worst practice	Impact under best practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland and other wooded areas	Unvegetated or sparsely vegetated habitats	Agricultural, horticultural and domestic habitats	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants	Soil biota
Livestock breeding	↔	↔																
Artificial insemination	↔	↔																
Animal sexing	↔	↔																
Twinning	↔	↔									•						•	
Lifetime efficiency	↔	↔															•	
Cow multi-use	↔	↔																
Low emission housing	↘	↔									•	•	•					
Ventilation	↘	↔									•	•	•					
Manure temperature	↔	↔																

Animal house emissions filtration	↘	↔									●	●	●					
Tied systems	↔	↔																
Poultry Cages	↔	↔																
Reduce manure contaminated surfaces	↔	↔									●							●
Dry surfaces and animals	↔	↔									●							●
Urine absorption	↔	↔																
Slurry-based systems	↘	↔									●	●	●					
Rapid separation of urine & faeces	↘	↔									●	●	●					
Slatted floors	↘	↔									●	●	●					
Frequent manure removal	↓	↔			●						●							
Extend winter housing	↘	↗			●		●				●							
Fertiliser on demand	↔	↗			●		●				●				●		●	
Pasture age & composition	↓	↘					●				●					●	●	●

High sugar grasses	↓	↘														●	●	●
Increase N fixation	↔	↗					●				●					●	●	●
Adjust groundwater levels	↓	↘			●	●	●	●			●		●	●	●	●	●	●
Arable to grassland	↘	↗					●				●	●	●	●	●	●	●	●
Cattle winter management	↔	↗					●				●				●		●	
Fast growing trees	↘	↗					●				●	●	●			●		●
Irrigation	↘	↗			●		●				●				●		●	
Supplementary feeding	↘	↔					●				●						●	
Relocation of pasture	↘	↔			●		●	●		●	●	●	●	●	●	●	●	
Reduced stocking rate	↘	↑					●				●		●		●	●	●	
Optimise plant & animal prod^{n}	↘	↑			●		●				●	●	●	●	●	●	●	
Fodder and forage analysis	↔	↔					●				●		●			●	●	
Forage quality improvement	↘	↔					●				●					●	●	●
Reduce feed imports	↘	↗			●	●	●	●	●	●	●	●	●	●	●	●	●	

Mechanical feed treatment	↔	↔									●							●
Chemical feed treatment	↘	↔									●					●	●	●
Livestock feeding optimisation	↔	↔									●							●
Feed additives	↓	↔												●	●			●
Airflow over slurry	↔	↗					●				●	●	●			●	●	
Manure temperature	↔	↔									●							●
Manure pH	↔	↔									●							●
Manure additives	↔	↔			●										●		●	●
Slurry surface area	↔	↔																
Separation of slurry/solids	↔	↔																
Added solids/ composting	↔	↔			●		●				●				●			
Denitrification	↔	↔									●							●
Stirring	↔	↔																
Filling slurry underneath	↔	↔																

FYM storage	↔	↔									•							•
Slurry storage	↔	↔																
Anaerobic digestion	↔	↔																

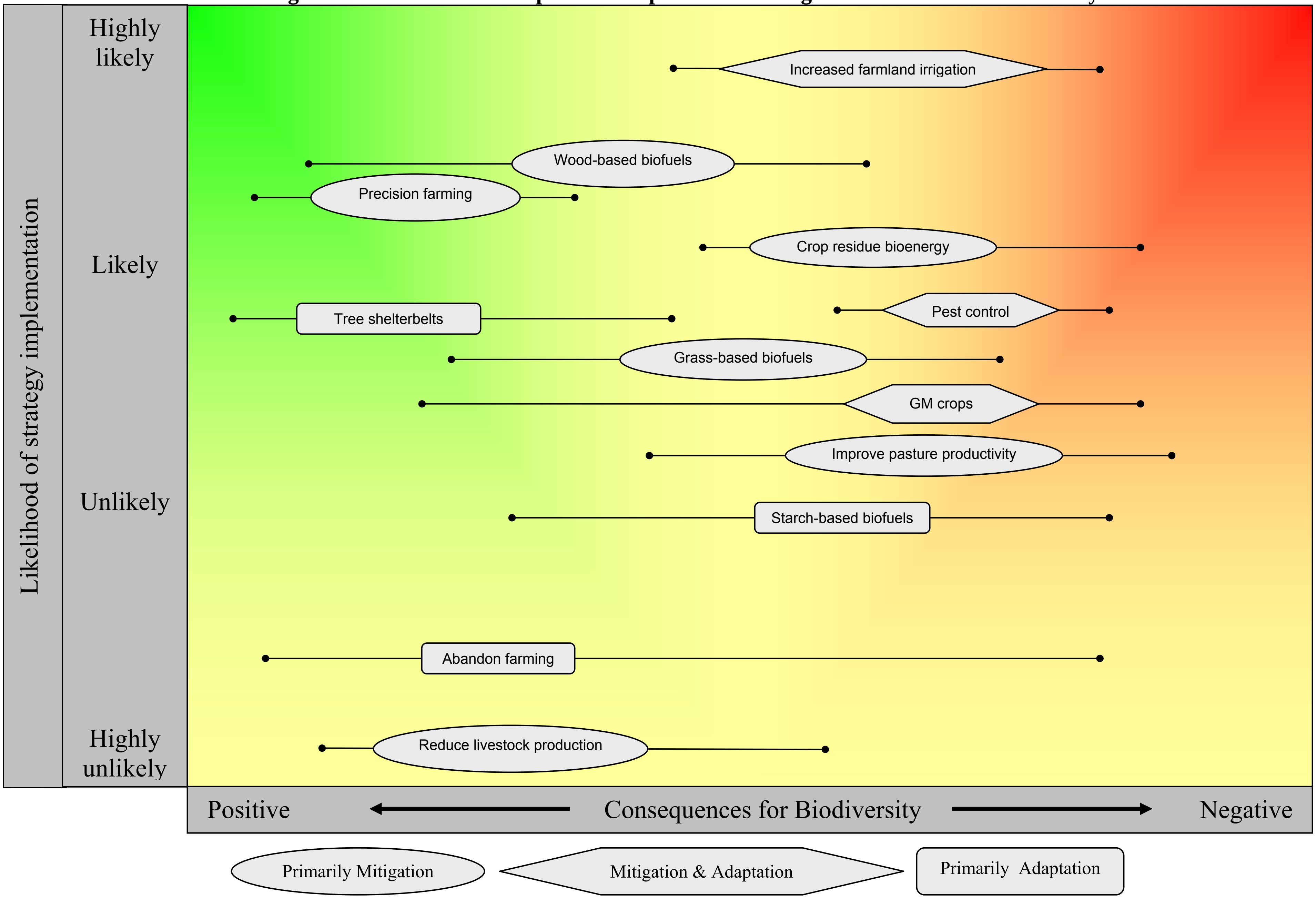
Crop Production Mitigation or Adaptation Strategy	Biodiversity Impact		Habitats affected									Taxa affected						
	Impact under worst practice	Impact under best practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland and other wooded areas	Unvegetated or sparsely vegetated habitats	Agricultural, horticultural and domestic habitats	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants	Soil biota
Cover crops	↘	↗				•	•	•	•	•	•	•	•	•	•	•	•	•
Water management	↘	↔			•						•	•	•	•	•	•	•	•
Soil compaction	↔	↗			•		•				•	•	•	•	•	•	•	•
No-till	↘	↗									•	•	•			•	•	•

Precision farming	↔	↗			●	●	●	●	●	●	●	●	●	●	●	●	●	
Winter/spring cultivars	↘	↗									●	●	●			●	●	●
N use efficient cultivars	↔	↗			●						●	●	●			●	●	●
Drought tolerant cultivars	↔	↗			●						●				●			
Deep rooted crops	↔	↔									●				●			●
GM crops	↓	↗			●	●	●	●	●	●	●					●	●	●
Perennial grain crops	↔	↗									●	●	●			●	●	
N-fixing crops	↔	↗			●						●				●	●	●	●
Precision crop nutrient	↔	↗			●						●				●	●	●	
Organic nitrogen	↘	↗									●				●		●	●
Soil infiltration rate	↘	↔			●						●				●		●	
Manure additives	↘	↔									●						●	●
Slurry application	↘	↔			●						●				●		●	●
Manure incorporation	↔	↔									●							●

Residue management	↘	↗			•						•					•	•	•
Land-use change	↓	↑			•	•	•	•	•	•	•	•	•	•	•	•	•	•
No-till	↘	↗									•	•	•			•	•	•
Shallow water table	↔	↗			•	•	•				•	•	•	•		•	•	•
Bare fallow reduction	↓	↑			•						•		•			•	•	•
Energy crops	↓	↑			•	•	•	•	•	•	•	•	•	•	•	•	•	•
SRC bioenergy	↔	↑					•				•	•	•	•		•	•	•
Grasses bioenergy	↘	↑					•				•	•	•	•		•	•	•
Crop residue bioenergy	↘	↗									•	•	•	•		•	•	•
Sugar and starch biofuel	↘	↔									•	•	•	•	•	•	•	•
Oil and cereal biofuel	↘	↔									•	•	•	•	•	•	•	•
GM use in bioenergy	↘	↔					•	•	•	•	•						•	
Land-use	↘	↗				•	•	•	•	•	•	•	•	•	•	•	•	•
Displacement	↓	↘			•	•	•	•	•	•	•	•	•	•	•	•	•	•
Operating time changes	↘	↗									•				•		•	•

Pesticide use	↘	↗			●						●	●	●	●	●	●	●	
Integrate plant & animal	↘	↗			●		●				●	●	●	●	●	●	●	
Extensification	↔	↗					●				●	●	●	●	●	●	●	●
Intensification	↘	↔			●	●	●	●	●	●	●	●	●	●	●	●	●	●
Increase grazing, reduce housing	↘	↗			●						●	●	●	●	●	●	●	
Increase grazing to arable	↘	↗									●	●	●	●	●	●	●	
Organic	↔	↑			●	●	●	●	●	●	●	●	●	●	●	●	●	●
Abandon	↓	↑									●	●	●	●	●	●	●	●
Microclimate	↘	↗				●	●	●	●	●	●	●	●	●	●	●	●	

Figure 2: Risk matrix for impacts of adaptation and mitigation measures on biodiversity



2.7.2 Gaps in knowledge and research needs

There are clear and obvious gaps in the analysis above where we do not know how a particular measure will impact on biodiversity (perhaps the best example is with GM technology). Despite making inferences from relevant published material it is sometimes difficult to predict the impacts of some measures; which is compounded by several other factors:

- The variability in management practice for any given measure at the farm scale.
- Differences in local habitats, climates, soil types, etc.
- Some measures may work well together or they may work antagonistically.
- Future socio-economic climate.

Despite these difficulties it is still possible to predict with some confidence how many of these measures will impact on biodiversity. However, with further detailed analysis of EU25 agri-environments, the associated habitats and species, localised farm practices, the most likely mitigation/adaptation measures etc., it would be possible to fine-tune and identify the most likely harmful mitigation and adaptation measures. The development of an adaptable risk analysis framework to enable predictions of how any given measure would affect a species or habitat would be very useful. The use of risk analysis frameworks has been applied mainly in biological hazard, pathogen and toxicity reports as well as building engineering; although they are becoming more widely applied in ecological contexts. One recent development offers an attractive prospect for analysing mitigation and adaptation measures.

Butler et al (2007) recently published work on a risk-assessment framework designed to predict the impact of environmental changes on farmland biodiversity. The model was tested on birds and looked at the effects of two different management scenarios: the use of genetically modified herbicide resistant crop and the adoption of agri-environment schemes. This approach drew on bird species traits (in this case, diet, foraging habit and nesting habit) to investigate how a given environmental change would affect the species habitat requirements. A risk score was calculated on an assumption that species with broader niches (i.e., wider diet, foraging and nesting habitat) would be less vulnerable to change than those with narrower niches.

The beauty of the analysis is that it could easily be applied to other environmental change situations using different taxa (and trait databases are increasingly being developed – for Europe see: Ellenberg et al., 1991; Fitter and Peat, 1994; Hill et al., 1999; Klimes and Klimesova, 1999; Knevel et al., 2003; Hill et al., 2004; Grime et al., 2007; Billeter et al., 2008); as long as sufficient trait data are available the environmental impact could be estimated. This approach has limitations but it would offer a very useful guidance for policy makers, particularly as it is transferable across different sectors.

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3. Forestry

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3.1 European forests and climate change

The Intergovernmental Panel on Climate Change (IPCC, 2007), as well as several reviews (e.g., Winnett, 1998; Koskela et al., 2007), suggest that forests are highly sensitive to climate change. Although changes at regional or local scales are difficult to forecast, at global scales major shifts in the area occupied by forest biomes are predicted with tropical and temperate forests expanding and boreal forests declining when other factors are ignored (Loehle, 2000; Ostendorf et al., 2001; Peñuelas & Boada, 2003; Thuiller et al., 2006). Potential impacts of climate change on European forests vary, including both positive and negative growth responses (e.g. Kellomäki et al., 2000; Sabaté et al., 2002; Schröter et al., 2005), partially because of large regional differences in the sensitivity of forests. Populations at the southern or continental distribution limits are expected to have strong productivity loss, weakened competitive ability and hindered sexual reproduction (Mátyás, 2000) while in northern Europe the productivity of forests is likely to increase. However storms may become more frequent in the north of Europe, and pests and diseases are likely to spread northwards. Overall, mixed forests are likely to be able to withstand a broad range of climatic conditions better than monocultures and broadleaved species are more susceptible to disturbance than conifers.

3.2 Mitigation and adaptation potential of forests

As globally important storehouses of carbon, forests play a critical role in influencing the Earth's climate. The forestry sector, including forest management activities and deforestation, is currently the source of 17.4% of annual greenhouse gas emissions (IPCC, 2007). The average amount of carbon stored in terrestrial biomass is 71.5 t/ha (FAO, 2007).

Five major strategies are available to mitigate carbon emissions through forestry activities: (1) to reduce emissions from deforestation and degradation, protecting important carbon sinks; (2) to increase forested land area through afforestation and reforestation; (3) to increase the carbon density of existing forests at both stand and landscape scales with different management alternatives; (4) to use harvested wood for products with a long lifespan (construction timber[5]); and, (5) to expand the use of (short lifespan) forest products that sustainably replace fossil-fuel CO_2 emissions.

A combination of reduction of greenhouse gas emissions from forest processing and an increase of measures to protect, restore, and sustainably manage forests thus offer significant climate change mitigation potential. However, climate change itself can affect the mitigation potential of forests (native and plantations), with differences in magnitude and direction for different regions. Thus, in addition to mitigation strategies, the forestry sector is debating a broad range of adaptation strategies to help forested ecosystems and services accommodate changes. Synergies between mitigation and adaptation strategies are often neglected, but some mitigation projects, for example, forest and biodiversity conservation, protected area management and sustainable forestry, indeed reduce vulnerability and promote adaptation. Ravinandrah (2007) points out:

- There is a need to ensure that mitigation strategies do not increase the vulnerability of forest ecosystems and plantations, i.e. that mitigation does not reduce the adaptation capacity of forests and forestry.
- Adaptation practices could be incorporated into mitigation projects to ensure or improve mitigation potential by reducing forest vulnerability.

Importantly, unlike in agriculture, adaptation measures for forestry need to be planned much before changes in growing conditions take place, because the forests regenerated today will have to cope with the climate conditions of the next 60 to 100 years. Adaptive strategies include resistance options (to maintain a relatively constant state in the face of stress), resilience options (to promote rapid recovery after a disturbance) and response options (facilitate transition of ecosystems from current to new conditions) (Millar et al., 2007).

Resistance approaches aim at improving forest defences against various effects of climate change, whether direct or indirect. Typical resistance strategies include the reduction or prevention of fires, insect outbreaks and diseases (Agee and Skinner, 2005) by making use of herbicides, pesticides and fertilizers as well as breeding of resistant lines. Resistance options are expensive and only a short-term solution, or preferably applicable to forests with low sensitivity to climate.

Resilience enhancing strategies are those more often promoted (Spittlehouse, 2005; Millar et al., 2007). These are strategies that allow the forest to tolerate disturbances and recover quickly. Connectivity, heterogeneity and diversity at

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[5] In a broader sense, when considering the effects of forest management one should also consider the life cycle of the forest products removed (Harmon et al., 1990; Eriksson et al., 2007). If all the wood harvested is used for products with a long lifespan (for example, construction timber in buildings instead of concrete), much more C will be gained. Also, when the forest products are used for short-lifespan products, such as biofuel, instead of using fossil fuels, there will be an important net gain of C (Eriksson et al., 2007), although C storage in soil, biomass and forest products is lower.

the landscape level facilitate forest resilience. Other costly and demanding actions include surplus seed-banking (Ledig and Kitzmiller, 1992) and, for example, intensive management during re-vegetation in the early years of establishment.

The third type of adaptation approaches accept and *facilitate the response of forest ecosystems to changes*. Treatments should assist or enable ongoing natural adaptive processes such as species dispersal and migration, population mortality and colonisation, changes in community composition or species dominance and changing disturbance regimes. For forest plantations, examples would include modifying rotation times, altering thinning procedures, and replanting with different species, or with populations from other parts of the distributional range (e.g. from lower elevations or latitudes). These are likely to be most cost-effective long-term solutions and are often beneficial for biodiversity.

Nevertheless, most forest management strategies to mitigate or adapt to climate change neglect the effects on biodiversity, despite the fact that effects can be large. Moreover, it is important to note that biodiversity can, in turn, play a role in making the forests less vulnerable to climate change, as higher species richness increases tolerance to environmental extremes and greater temporal stability and recovery potential (e.g., Tilman, 1999).

3.3 Biodiversity in European forest ecosystems

The world's natural forests hold more biodiversity than any other environment, but they are also one of the most threatened. So far, despite the commitment for halting the loss of biodiversity by 2010, Europe's efforts for forests have had mixed results, especially when one looks at the number of threatened species (EEA, 2008).

The share of the number of threatened tree species of the total forest tree species in European countries varies from 10 to 15%, with the largest number of threatened forest tree species found in Serbia. When considering also herbal plants, the number of threatened forest vascular plant species per country ranges from 14 to 771, with numbers being largest for Central and East European countries (Köhl and Rametsteiner, 2007).

Out of 195 bird species listed in Annex I of the Birds Directive, 67 are forest-related, of which 7 are globally threatened. Populations of common forest birds have show a decline of 9% in Europe, particularly in the Northern boreal forests and in the Southern Mediterranean forests between 1990 and 2005 (EBCC, 2007). For European mammals, the IUCN undertook the first comprehensive assessment across all 25 EU Member States in 2007 and concluded that out of 104 mammal species which depend on forests, two are critically endangered (the Bavarian vole *Microtus bavaricus* and the Iberian lynx *Lynx pardinus*), three are endangered (bats from the Macaronesian region: *Nyctalus azoreum,* *Pipistrellus maderensis* and *Plecotus teneriffae*), six are vulnerable (the bison *Bison bonasus*, the wolverine *Gulo gulo*, the Corsican hare *Lepus corsicanus* and three further bat species *Myotis bechsteinii, Plecotus sardus* and *Rhinolophus euryale*) and eleven are classified as near-threatened (four bat species *Myotis dasycneme, Myotis punicus, Rhinolophus ferrumequinum* and *Rhinolophus hipposideros,* the European rabbit (*Oryctolagus cuniculus*, the Siberian flying squirrel *Pteromys volans*, the garden dormouse *Eliomys quercinus*, the wild cat *Felis silvestris*, the western polecat *Mustela putorius*, the brown bear *Ursus arctos*, and the lynx *Lynx lynx*) (IUCN, 2007).

Several mammals and birds use hiding and nesting places in dead trees or forage on invertebrates living in deadwood or coarse woody debris. Deadwood is an important substrate for a large number of forest species such as insects and other invertebrates, lichens, bryophytes and fungi. In Fennoscandian forests as much as 20–25% of all known forest-dwelling species may depend on dead-wood habitats (Siitonen, 2001). Quantities of deadwood in Europe have greatly decreased since the nineteenth century due to intense forest exploitation. For instance, the volume of dead wood in southern Fennoscandian managed forests may have been reduced by as much as 92–98%, compared to pre-industrial old-growth conditions (Siitonen 2001). Because of a lack of deadwood in production forests, many of the dependent saproxylic species, which number in their hundreds, are in danger of being lost (Hanski, 2000).

Classical forest management is usually based on rotations that are shorter than natural longevity of tree species and so the number of old big trees in forest is usually low. However, nowadays, in many European countries, initiatives have been taken to increase the amount of deadwood in forests. This may be countered by the increased interest in forests for energy production though.

3.4 Forestry measures for mitigation and adaptation and their effects on biodiversity

In the following paragraphs we review main forestry measures with different potential impacts on biodiversity.

3.4.1 Reduced deforestation

17.4% of the annual anthropogenic greenhouse gas emissions come from the forestry sector (IPCC, 2007) and a large share of this is attributable to deforestation. Reduction of deforestation and establishment of forest protected areas are seen as the strategies with the most positive impact both on carbon sequestration and biodiversity conservaton (Ravindranath, 2007). Protection of existing mature forests and re-growing forests provides substantially greater carbon mitigation than replacing them with intensively harvested biomass production or plantations of fast-growing, alien, species (Huston & Marland 2003; García-Quijano et al., 2008). Although it was previously believed that old-growth forests were carbon neutral, and that as they age, they stop accumulating carbon, a recent study demonstrates that in forests between 15 and 800 years of age, net ecosystem productivity is positive, and thus old-growth forests serve as a global carbon dioxide sink (Luyssaert et al., 2008). Old-growth forests accumulate carbon for centuries and many currently contain have high carbon levels; but much of this carbon, even soil carbon, will move back to the atmosphere if these forests are disturbed. Instead, young forests rather than old-growth forests, are very often sources of CO_2 because the creation of new forests frequently follows disturbance to soil and vegetation, resulting in a decomposition rate of coarse woody debris, litter and soil organic matter that exceeds the net primary productivity of the re-growth (Harmon et al., 1990; Janish et al., 2002). Furthermore, old-growth forests have great potential to resist unfavourable climatic conditions over long time periods, and can therefore buffer the adaptation of inhabiting species to new conditions (Noss, 2001).

However, old-growth forests are not protected by international treaties. The Kyoto Protocol only considers anthropogenic effects on ecosystems, so that the accounting for changes in carbon stock by afforestation, reforestation and deforestations is mandatory. Unfortunately, leaving forests intact was not perceived as an anthropogenic activity. Luyssaert et al., (2008) report that over 30% of the global forest area is unmanaged primary forest, and half of the primary forests are located in the boreal and temperate regions of the Northern Hemisphere. These forests alone sequester about 1.3 ± 0.5 Gt of carbon per year.

Despite the enormous importance of forests as carbon storages and biodiversity harbours, they are cut down and/or converted for various reasons (about 13 million hectares per year, the net loss of forest area being about 7.3 million hectares/year in the 21st century: FAO, 2007). The net loss has been largest in tropical regions, and has resulted in substantial losses in carbon stored in forests with approximately 1.1 Gt loss each year during 1990-2005 (FAO, 2006). Gullison et al., (2007) estimate that reducing rates of tropical deforestation by 50% by 2050, and stopping deforestation when countries reach 50% of their current forested area, would avoid emissions equivalent to 50 Pg C, in addition to protecting the sink capacity of forest for continued removal of atmospheric CO_2.

Even though deforestation continues in developing countries, Europe and North America have reversed centuries of deforestation and are currently showing a net increase in forested areas. For Europe, the increase has been of 7% in the period 1990-2005, while the net global loss in forest area for the same time period was of 3%. Slightly less than half of Europe's net increase in forest area over the past 15 years results from an increase in forest plantations. The rest results from natural expansion of forests into former agricultural land and the establishment of "semi-natural" planted forests using native species. Nonetheless, only 4% of Europe's forest area (excluding the Russian Federation) is classified as primary forest (FAO, 2007) compared with 27% of the world as a whole. Also noteworthy, as much as 87% of the total area covered by forests in Europe is subject to some degree of human intervention. For instance, the area of semi-natural forest in the Czech Republic, Latvia, the Netherlands, Poland, Slovakia and Switzerland, is reported to make up 100% of the total forest area (Köhl and Rametsteiner, 2007). The area of plantation forest in the EEA region has also increased over the last 15 years from 10.9 to 13.3 million hectares (Köhl and Rametsteiner, 2007); although plantations are not evenly distributed, they dominate in Denmark, Iceland, Ireland and the United Kingdom. In Malta, all the forests are plantations.

About 3% of the forest and other wooded land has been protected in 35 European countries. Over half of this area is located in the Russian Federation. Excluding the Russian Federation, the area protected for biodiversity is 8% of the forest and other wooded land.

Smith et al., (2003) have shown that areas with high biodiversity values coincide with those that have poor governance and where corruption is common. For this reason, attempts to conserve forests and biodiversity often fail due to, e.g., illegal logging. The problem is all but marginal; it is estimated that in 2003 as much as 73-88% of timber in Indonesia was logged illegally (Schroeder-Wildberg and Carius, 2003). Given the illegal nature of the activity, exact figures are not easily assessed, but the most reliable estimates indicate more than a considerable share, in some cases more than the half of all logging activities in particularly vulnerable region. Disturbingly, almost one-fifth of wood imported into the European Union in 2006 came from illegal or suspected illegal sources, with Russia, Indonesia and China being the main sources (WWF, 2008).

A great deal of illegal logging activity takes place in national parks and protected areas, which is detrimental to the diverse ecosystems they are expected to protect. Importantly, the drivers of illegal logging are international: global demand for timber is increasing, and devastating amounts of forest is converted for palm oil production, with shift of logging pressure towards national parks and protected areas. Thus, challenges for international bodies include the needs to create policies to ensure that imported wood products are produced sustainably and that their production does not lead to deforestation or compromise the biodiversity values of primary forests.

Illegal logging is not only a problem outside Europe: the amount of illegal logging in the Baltic region and in the Balkans can be high (WWF, 2005a,b; Bouriaud, 2005). For instance, although figures vary, in Estonia the amount of illegally harvested timber has been reported to be as high as 50% (Estonian

Green Movement, 2004; WWF, 2003), in Latvia, between 15 and 25% (WWF, 2003), and in Russia between 20 and 50%.

The reduction of deforestation is the soundest measure for mitigation and adaptation. Main strategies to reduce deforestation include the protection of mature, especially primary forests but also the control of illegal logging and the control of timber imports. All these actions are both mitigation (protection of carbon sinks) and adaptation strategies (mature forests have larger chances to respond and adapt to climate change). Deforestation is one of the major causes of species endangerment, and establishing protected areas is the principal defence. Thus the impacts of reduced deforestation on biodiversity are positive, and more positive the larger and better connected the parcels of old growth forests. The maintenance of representative forest types across environmental gradients, the prevention of fragmentation, and the promotion of connectivity and buffer zones are identified as key strategies to facilitate adaptation of forest and forest associated species in rapidly changing conditions.

3.4.2 Afforestation

Forests have a higher carbon density than other types of ecosystems. The terrestrial carbon pool has been greatly reduced by human activities such as conversion of forests into agricultural land and urban areas. The afforestation of former agricultural land increases the carbon pool in the aboveground biomass and replenishes the soil carbon pool. In a European perspective, afforestation provides a great potential for carbon sequestration in agricultural soils (Powlson et al., 1998).

Conversion from agricultural land to forest means a shift from a shorter to a longer circulation time of carbon, as annual crops are replaced by long-lived perennial trees. Processes in the soil are complex though and whether soil becomes a source or a sink of carbon depends on the balance between litter production and decomposition. The storage capacity and rate of carbon sequestration depend on various factors such as the climate, soil type, tree species used for afforestation, current forestry practices, pre-afforestation management and land use history (Post & Kwon, 2000).

Afforestation of former arable land may serve many purposes and provide many benefits, including carbon sequestration, reduction in nitrate pollution of water bodies and biodiversity conservation or restoration. Nevertheless, afforestation may also have adverse environmental effects. A recent study (Rosenqvist, 2007) shows that afforestation of former arable land in north-western Europe largely improved environmental conditions: carbon was sequestered in biomass and soil and the quality of recharging soil water in terms of nitrate was improved. However, afforestation led to a reduction in water recharge to the groundwater, to soil acidification and nutrient deficiency.

Forests use more water than shorter types of vegetation. Farley et al (2005) found that annual runoff was reduced on average by 44% and 31% when grasslands and shrublands were afforested, respectively. Similarly, Jackson et al (2005) reports reductions on stream flow of between 38% and 52%, on a global study of afforested grasslands, croplands and shrublands. Eucalypts, a genus with great potential in a warmer European climate, have a larger impact than other tree species in afforested grasslands (e.g., compared with pines - Farley et al., 2005). The possibility that afforestation could cause or intensify shortages of water in many locations is a trade-off that should be explicitly addressed.

Previous land use affects the carbon sequestration potential of afforested sites. Pasture soils already have high carbon stocks and high root densities in the upper part of the mineral soil, so afforestation has a small effect (Guo and Gifford, 2002). Studies from transformed pastures in New Zealand, arable land in Spain and peatlands in northern England found that soils initially lost, but later gained carbon (Romanyá et al., 2000; Halliday et al., 2003 and Zerva et al., 2005). In contrast, croplands are more depleted in soil C, and have a greater potential to sequester soil carbon.

In general, afforestation of abandoned pastures or intensively managed agricultural land, typically inhabited by a highly impoverished flora and fauna, usually benefits biodiversity bringing conservation gains. This is particularly true in regions that have experienced significant losses of natural forests. In such situations plantation forests often facilitate the restoration of natural forest elements. In tropical regions, according to Kirby and Potvin (2007), afforesting agricultural lands for agroforestry would be a beneficial solution for biodiversity, but avoiding intensively managed plantation of alien tree species. As forests have the potential to hold water and regulate (stabilize) local climate, agroforestry might also enhance resilience of agriculture to changing climate in the tropical region (Verchot et al., 2007).

But biodiversity is often negatively impacted if afforestation takes place on natural or semi-natural open habitats, as forests replace native and possibly unique ecosystems. Afforestation of grasslands is likely to reduce stream flow and might lead to soil acidification and loss of nutrients (Jackson et al., 2005). Allan et al (1997) report that afforestation has had negative impacts on grassland-bird diversity, even when the percentage area under plantation is relatively low. Oxbrough et al (2006) and Buscardo et al (2008), compared afforestation impacts on a different types of grasslands and peatlands. Both studies affirm that semi-natural wet grasslands should not be afforested, unless similar habitats are abundant in the landscape. However, the effect of afforestation on improved and semi-improved grasslands should be neutral or positive, especially in landscapes that contain little semi-natural woodland habitat. Afforestation of peatlands should generally be avoided because of their biodiversity and rarity status (Oxbrough et al., 2006). Additionally, afforestation of peatlands negatively affects the greenhouse gas balance of such ecosystems (van Wesemael and Lambin, 2001).

Since forests have a great potential for storing carbon as they grow, afforestation offers a valuable opportunity to reduce atmospheric CO_2; however, afforestation can also provide adaptation when well planned. There are a number of uncertainties related to the mitigation potential, the adaptation benefits and the impacts on biodiversity of afforestation, that mostly depend on where and what is planted and how it is managed (see Plantations and Management below). Support for afforestation can cause the loss of non-forest habitats based on traditional land uses with high ecological value, if the incentives for afforestation are higher than for the traditional use or conservation measures. The location or land-type on which afforestation projects take place is thus of paramount importance. Planting forests on native grasslands, wetlands, shrublands, heathlands or peatlands may lead to dramatic biodiversity losses, and at the same time lower the relative increase in carbon sequestered compared to implementing such projects on degraded land. In general, afforestation should be most beneficial in highly modified open landscapes of the temperate zone.

3.4.3 Reforestation

Reforestation under the Kyoto Protocol covers forestation of areas that did not contain forest in the end of the year 1989, although some nations have asked for a ten-year shift in this time limit. Schulze (2003) presents the concern that such a shift might lead to deforestation and degradation of pristine forests that could then be reforested in order to get carbon credits.

Mitigation benefits of reforestation are estimated to be highest in the tropics, as they are enhanced by positive biophysical changes such as cloud formation which further reflects sunlight. Conversely, climate models suggest that large reforestation programs in boreal regions would have limited climate benefits because of the substitution of bright snow-dominated areas for dark forest canopies (Betts, 2000; Canadell and Raupach, 2008).

Plantations are also being used successfully to help dry waterlogged soils and alleviate flooding (Plantinga and Wu, 2003). The co-benefits of reforestation on water and soil resources may be the greatest where former forests have been replaced by crops, potentially restoring water quality and recharge to pre-agricultural levels (Plantinga and Wu, 2003). Reforestation of floodplains can also be beneficial for reducing erosion, improving water quality, mitigating peak flows, controlling groundwater discharge (upwelling) and promoting the maintenance of biodiversity. Also noteworthy, this does not hold for monoculture plantations that maximize carbon sequestration but have considerable impact on runoff and groundwater recharge.

Reforestation is mainly achieved through direct planting of seeds or seedlings. While planting seeds used to be the most common way, planting seedlings has become more popular with increased mechanical site preparation, improved seedling quality and higher guarantees of success. However, planting seedlings is not always possible when extensive areas need to be reforested. Reforestation with seeds often occurs with less disturbance and thus lower ecological impacts.

An important issue in reforestation projects is the balance between natural and artificial regeneration, i.e. to what extent should natural regeneration be used and when to encourage planting of seeds or seedlings, possibly originating from different climatic conditions. The occurrence of frequent natural regeneration is fundamental for continuous natural selection in forest ecosystems, thus maintaining the evolutionary process of forest tree populations. Artificial regeneration may be needed to complement natural regeneration and, in some cases, to accelerate the adaptation of forest trees to climate change (e.g., by using more southerly provenances).

Forest recovery, especially of tropical forests, is slowed by a number of factors, including a lack of adequate seed dispersal and microclimatic extremes. The plantation of islands of trees in abandoned pastures has shown to speed up the recovery, as isolated trees are used by birds and bats that contribute to long-range seed dispersal and pollination, also increasing the structural and genetic connectivity of fragmented forest landscapes. Recently, studies have also shown that artificial bat roosts can be a valuable and inexpensive tool for the reforestation of neotropical habitats, enhancing at the same time the conservation of these mammals in highly modified lansdcapes.

In areas with a long history of human exploitation, the physical environment has often been largely modified and extensive planting is needed to recover the vegetation. Where restoration fails because of highly modified soils or harsh environmental conditions, species that minimize these effects can be used as nurse plants to facilitate the establishment of target tree species. Facilitation is an essential process for survival, growth and fitness in some plants, but also for diversity and community dynamics in many ecosystems (Kikvidze et al., 2005), particularly on drylands, alpine areas or other limiting or degraded habitats. Non-invasive exotic species have been used as a nurse crop to assist the recovery of nutrients in highly degraded soils; but the use of exotic species should mostly be discouraged. Recently, several studies have shown that native natural plants (shrubs and herbs), make good nurse plants and enhance restoration in alpine areas, semi-arid steppes, arid shrublands, coastal wetlands and degraded and burnt sites (Padilla and Pugnaire, 2006). In a study in the Mediterranean region, Castro et al (2004) found that nurse shrubs decreased mortality in two mountain pines without inhibiting their growth.

They conclude that the use of shrubs as nurse plants for reforestation increases establishment success in Mediterranean-type ecosystems and that it might be similarly useful in other water-stressed environments. In addition, this technique minimizes the impact in the community as it follows natural succession. Such results directly contradict traditional reforestation management practice, where shrubs are removed prior to tree planting due to their presumed competitive effects on tree seedlings. The facilitative effect of nurse plants in dry environments may be caused by different mechanisms including: providing shade that protects understory species against high irradiance and temperatures, keeping higher soil moisture and lower transpiration, improving the water status of the understory species, enhancing water availability actively via hydraulic lift, increasing nutrient availability because of an accumulation of litterfall and because of higher moisture, which accelerates nutrient cycling, improving physical and chemical soil properties and providing defence against large herbivores.

Factors such as the choice of tree species and their combinations will largely affect the potential benefits of both afforestation and reforestation. The following sections address some of these issues.

Planting trees on formerly forested land can enhance biodiversity and environmental services, especially when native species are used, and when natural plants are used as nurse plants to facilitate establishment in harsh environments. Reforestation (and afforestation) activities designed to mitigate climate change can restore watershed functions, establish biological corridors and provide considerable biodiversity benefits as long as a variety of different aged native tree species are planted. Monocultures, however, not only reduce biodiversity, but also have higher risks of pest attacks, and thus challenge the permanence of carbon stocks. Additionally, monocultures worsen the adaptation capacity of forest to climate change. Some studies indicate that the most promising mitigation practices are reforestation in the tropical latitudes, and reforestation and afforestation in the temperate regions.

3.4.4 Plantations

3.4.4.1 Tree species

The carbon storage capacity is in many ways determined by the choice of tree species. For instance, at identical biomass volumes, trees with a high wood density (many deciduous tree species) accumulate more carbon than trees with light wood (many coniferous species). On the other hand, conifers sequester carbon more effectively and store it longer than ecosystems dominated by deciduous trees. This is because the growth rate of many coniferous species is higher over longer periods than that of many deciduous species, and because the decomposition rate of coniferous litter is generally lower than that of deciduous litter. However, several of the temperate broadleaved tree species are better adapted to climate change and, in addition, the conifer plantations have in many cases proven to be unstable when exposed to climate extremes such as very wind conditions, drought and associated bark beetle attacks.

The use of alien invasive tree species for forest establishment adversely affects environmental services with potentially large negative side-effects. There are several examples where non-native tree species have become invasive in the area of introduction, altering natural habitats outside the plantation (e.g., Moran et al., 2002; Richardson 2006). Even if the introduced species does not become invasive, it often results in decreased diversity within the plantation (Caparros & Jacquemont, 2003).

3.4.4.2 Monoculture vs. mixed plantations

Mixed plantations are preferred to monoculture plantations for a number of reasons such as increased resistance to pests and diseases (Jactel et al., 2005), reduced risk of wind-throw (Dhôte, 2005) and increased biological diversity (Hartley, 2002; Jones et al., 2005; Kelty, 2006). Tree monocultures, such as energy tree plantations or plantations of fast growing alien species like eucalyptus do not contain the same biodiversity values as primary forests (Caparros & Jacquemont, 2003; Garcia-Quijanno et al., 2007). The bird fauna of single-species plantation forests has been reported to be less diverse than that of natural or semi-natural forests (Helle and Mönkkönen, 1990; Baguette et al., 1994; Twedt et al., 1999). Carabid beetles were found to be more abundant and diverse in natural or semi-natural forest than in spruce plantations in Ireland (Fahy & Gormally, 1998) and Hungary (Magura et al., 2000). Similar results were obtained in studies of beetles in South Africa (Samways et al., 1996), dung beetles in Borneo (Davis et al., 2000) and arthropods in general in Brazil (Chey et al., 1998) and New Zealand (Anderson and Death, 2000). The vegetation in conifer plantations was found to be less diverse than that in semi-natural woodlands in Ireland (Fahy & Gormally, 1998) and in Great Britain (Humphrey et al., 2002).

Although still controversial, monocultures of fast growing species are thought to generate higher revenue than mixed species forests. Nonetheless for the productivity of a forest over the entire rotation period, its stability against disturbance is important. Thus Spiecker et al (2004) propose the conversion of Central European secondary Norway spruce plantations to mixed species to reduce the risks of damage caused by storm, snow, ice, drought, insects and fungi, also upgrading biodiversity

3.4.4.3 Origin of seeds and seedlings

Measures to facilitate forest adaptability to changing and unpredictable future conditions include the incorporation of provenances from a wide range of localities, for example from sources at lower elevations or latitudes (Bawa and Dayanandan, 1998), rather than relying on local seed sources (which under relatively stable climatic conditions would be an appropriate strategy). Genetically diverse assembly of seedlings and increasing seedling plantation density are also preferred. According to Ledig and Kitzmiller (1992) this increases the odds that at least some of the seedlings would succeed and at the same time, genetic diversity among tree species is promoted. Planting mixed stands of multiple species improves forest adaptability as well, while creating a heterogeneous habitat (Resco de Dios et al., 2007).

3.4.4.4 Tree breeding

With the development of selection programmes to improve productivity and carbon sequestration and increase resistance, the level of genetic diversity of the planted material is, or has been, progressively lost. Less genetically diverse controlled mixtures of full-sib families, clonal varieties, or genetically modified trees can be expected to have a lower adaptability and an increased ecological risk (Evans, 1999). Genetic diversity ensures that forest trees can survive, adapt and evolve under changing environmental conditions. Ultimately, forest genetic diversity also has a crucial role in maintaining forest biological diversity. Diverse gene pools should be maintained within and among populations of commercially important trees and other forest species (Dudley, 1998).

Most tree improvement programs already stress genetic diversity but may better prepare for adaptation to climate change if testing selections in a wider set of environments than is now the case. Nevertheless, cautious tree breeding and transfer of potentially suitable forest reproductive material has the potential of accelerating adaptation of forests to climate change, facilitating migration of tree species and increasing the intensity of selection. Such strategies require the development of pan-European guidelines for the transfer of forest reproductive material in Europe.

Gene transfer is an appealing strategy being tested for most forest species undergoing intensively bred, such as Monterey pine, Scots pine, Maritime pine, Sitka spruce, Norway Spruce, Eucalyptus and poplars. Together with other modern biotechniques, rapid genetic gains can potentially be transferred to forestry. Transgenesis has been considered as an attractive tool for genetically improving trees for pest and insect resistance and increased economic efficiency of wood production with reduced use of pesticides (Jouanin, 2000).

But the risks for biodiversity are not negligible (Kremer, 2002). Dissemination of genetically modified material might result in introgression with related tree species (Matthews and Campbell, 2000) and in the spread, through natural regeneration, of genetically modified trees that are potentially better adapted to site conditions (Hayes, 2001). The extent to which transgenes will escape from cultivation and cause negative impacts in wild ecosystems is a major issue. Gene flow to wild relatives is of particular concern for forest trees because they are undomesticated, they have the potential for spatially extensive gene flow, and they can have large effects on ecosystem processes and biological diversity when they are the dominant life form. Reliable, tested and agreed protocols for evaluating risks associated with genetically modified trees are essential, but challenging in such long-term crops.

Policy-makers in Europe should recognize the importance of forest genetic diversity in mitigating the impacts of climate change on the forest sector by expressing a commitment at pan-European level to incorporate the management of this diversity into national forest programmes and other relevant policies, programmes and strategies. Regulatory frameworks for testing, monitoring and management of GMOs are essential. FAO intends to continue monitoring genetic modification technology and products in forestry at the global level and ensure availability of objective and reliable information.

Existing commercial plantations, or new plantations for afforestation and reforestation projects should preferably use native tree species, and mixed species stands (broadleaves and conifers), to enhance forest stability, and favour long-term mitigation and adaptation potential, as well as biodiversity values. The maintenance or increase in genetic diversity of forest trees is essential to enhance forest adaptability to changes, and also promotes biodiversity. The incorporation of provenances from a wide range of localities enhances adaptation to climate changes, also contributing to increased genetic diversity. The transfer of genetic material in tree breeding is gaining popularity but it implies potential risk for biodiversity and requires regulatory frameworks.

3.4.5 Forest management

Intensively managed forests behave as strong carbon sources following clear-cutting and site-preparation operations. Reducing damage to non-harvested trees and disturbance of forest soils during logging operations can substantially reduce CO2 emissions. Clear-cutting and mechanic soil preparation also increase forest vulnerability. Forestry practices that minimizes soil disturbance, size of canopy openings and removal of biomass will promote the resistance and resilience of forests to climate change more than intensive logging (Schelhaas et al., 2006). Net carbon sequestration can be achieved by increased forest carbon density, through both stand-scale management and landscape-scale strategies such as longer harvesting cycles and reduced disturbances.

3.4.5.1 Forest fires

In general, most of the strategies for forestry adaptation appear to be good mitigation strategies as well (e.g. forest fire control by thinning) (Agee & Skinner 2005) but they have moderate to negative impacts on biodiversity. Camprodon and Brotons (2006) have shown how the clearing of undergrowth as a fire control strategy has a negative impact for undergrowth-dwelling bird species, for shrubs and lianas, and potentially for arthropods. The use of herbicides and fertilizers, aimed at intensifying or retaining wood production, protecting forests from thermal and moisture stress and from pests and diseases, has potentially very damaging effects for non-targeted species

(Flueck, 2006). Forest fire management is a controversial issue; although forest fires are large emitters of CO_2, natural fire regimes are needed for the persistence and regeneration of many forest types and plant communities. Careful control of fires in some stands, especially for fires of anthropogenic origin can, though, be considered.

3.4.5.2 Pesticides and herbicides

Herbicide treatments and other intensive management measures can also deteriorate vegetation recovery destroying the linkage between plants and obligate mycorrhizal fungi. In contrast to temporary suppressive measures such as insecticide treatments, the control of pests and pathogens through forest diversification is preventive, long-lasting, has no adverse environmental impacts, and complies well with new guidelines for biodiversity-oriented and sustainable forest management. Both plant-species diversity and genetic diversity are assumed to mitigate pest and pathogen problems.

3.4.5.3 Felling rotation

Rotation time is also worth considering. Eriksson and Berg (2007) suggest that although short rotations result in more biomass and have larger potential for mitigation, they are more disturbing for biodiversity. Jukes et al (2001) showed that the numbers of forest-specialist carabids increased with increasing plantation age, supporting benefits on biodiversity from long-rotation times. Overall, trees grow quickly when they are young, but growth slows as they mature. Although shorter periods would enhance quicker response to various symptoms of changing climatic conditions, they incur a higher risk of depleting critical soil nutrients and facilitating species invasions. Given that longer rotation times increase the carbon stocks and are less detrimental for biodiversity, these should be preferred. A carbon market and a sound regulatory framework are needed to provide financial incentive to lengthen the harvest cycles.

3.4.5.4 Management in difficult circumstances

In general, in the core distribution area of widely dispersed tree species with effective gene flow, there is yet no need for preparatory measures if the stands have been properly managed and regenerated. Active preparatory measures should have priority in the case of rare, fragmented tree species with limited or impeded dispersal ability. Species occupying extreme habitats should also receive special attention. However, even major, widely distributed tree species need special consideration in the following situations: where there are isolated populations on the southern or continental fringes of the distribution area; in locations where conditions in the potential colonization area are unsuitable (high alpine or boreal conditions); where the areas were regenerated with reproductive material of obviously low adaptability (Koskela et al., 2007).

Forest management practices are critical in determining whether a plantation behaves as a carbon source or a sink. Clear-cutting as well as major soil disturbances should be avoided. Less intensively managed forests will become long-term positive mitigation and adaptation strategies, and at the same time benefit biodiversity. Longer rotation times are also preferred. Careful control of fires in some stands, especially for fires of anthropogenic origin can be considered, but complete fire suppression might be detrimental for biodiversity. Fertilizers, herbicides and pesticides, although enhancing the mitigation and adaptation potential of plantations, often have negative impacts for onsite biodiversity, and should be carefully considered when management practices cover large areas. Overall, silvicultural practices for the management of forests should focus primarily on stabilising measures.

3.4.6 Forest product management

Once wood is removed from the forest, its subsequent use affects its sequestration potential; when considering the effects of forest management one should also consider the life cycle of the forest products removed (Harmon et al., 1990; Eriksson et al., 2007). If all the wood harvested is used for products with a long lifespan (for example, construction timber in buildings instead of concrete), much more carbon will be gained. Also, when the forest products are used for short-lifespan products, such as biofuels, instead of using fossil fuels, there will be an important net gain of carbon (Eriksson et al., 2007), although carbon storage in soil, biomass and forest products is lower.

The forest product industry includes wood product manufacture, use, and disposal. Wood products are carbon stores, rather than carbon sinks. Their carbon continues to be stored through their lifecycle. After wood products have been used in one application, such as furniture, or construction, they can often be re-used or recycled, and eventually combusted to produce energy that can replace fossil fuels. The longer the life of these products, the greater the benefit to the environment.

3.4.6.1 Bioenergy

With the increase in demand for bioenergy, two main approaches are being sought. One relates to energy-plantations, i.e., plantations for the exclusive production of biofuels; the other takes advantage of logging residues that were formerly left to decay on clear cuts.

Large-scale biomass plantation projects like oil palm plantations in Malaysia, Indonesia and Thailand often entail the destruction of large areas of rainforest, reducing biodiversity, increasing vulnerability to catastrophic fires, and affecting local communities dependent on services and products provided by forest ecosystems (Fitzherbert, et al., 2008). Beyond the loss of forest ecosystems, the production of palm oil can be rather damaging to the environment. In 2001 Malaysia's production of palm oil generated 9.9 million tons of solid oil wastes, palm fibre shells and 10 million tons of palm oil mill effluent, a polluted mix with negative impacts on aquatic ecosystems. Palm-oil cultivation is not only polluting on a local level but also contributes to greenhouse gas emissions by generating this waste and by replacing important carbon sinks.

Despite this, oil palm can be cultivated in a manner that helps mitigate climate change and preserves biodiversity. An important step is avoiding the establishment of plantations in natural forest areas and peatlands. Oil-palm cultivation in both these areas does more harm than good, either through the reduction of biodiversity and ecological services (natural forests) or through the release of massive amounts of carbon dioxide (peatland conversion). As with other plantations, oil-palm plantations should be encouraged on existing agricultural lands and areas that have been heavily degraded and deforested. Financial incentives promoting the production of 'green palm oil' will reduce deforestation and therefore enhance mitigation outputs.

3.4.6.2 Harvesting by-products

Biofuels produced as by-products of clear-cutting are already an important energy resource worldwide as well as in Europe, especially in coniferous forests (Doherty et al., 2002). Slash and stump harvesting is likely to become more widespread both for bioenergy production and because it facilitates regeneration of commercial timber species (Hakkila, 2003). But the removal of this material affects forests biodiversity, especially species which depend on decaying wood and moist, dark microclimates for their survival. In Fennoscandia several thousand species belong to this group, including beetles, fungi and bryophytes. The removal of wood from managed forests has been proved to affect species composition of these groups, reducing species richness of liverworts and mosses (Åstrom et al., 2005) and carabid beetles, paralleled by an increase in abundance of generalist species (Nittérus et al., 2007).

Additionally, the reduced input of organic material and nutrients (Åstrom et al., 2005) leads to reduced tree growth (Egnell & Leijon 1999; Egnell & Valinger, 2002) and reduced abundance of soil arthropods (Bengtsson et al., 1997). Slash left in clear cuts provides shelter and structural heterogeneity important for small mammals that are negatively affected by the removal of these logging residuals (Ecke et al., 2002). Furthermore, slash harvest requires additional machinery and generates greater mechanical disturbance of the ground surface and it also enables more effective site preparation that increases soil disturbance (Hakkila, 2003).

All together, the removal of wood debris from managed forests has been identified as one of the main reasons for the decline and regional extinctions of many forest species, for example, in Fennoscandia (Berg, 1994; Siitonen, 2001). Thus, large-scale intensive biomass harvest should be avoided. If logging residues such as slash and stumps need to be extracted, careful spatial planning is required to retain wood residuals in some stands while removing it from others. In boreal forests, deciduous tree species, especially southern ones and aspen, should be retained as much as possible. Management practices should include retention of clustered trees with intact undergrowth and generation of coarse wooded debris (Larsson & Danell, 2001).

The use of forest products as a source of biomass energy can result in a conflict between climate mitigation and other environmental objectives. Besides residues from wood production additional sources of forest biomass, such as the removal of slash, are included in the evaluation of forestry bioenergy potential. Nonetheless, the use of forest residues has strong negative effects on species depending on decaying wood, and reduces ecosystem functioning. Managing for biomass should only be an option if deleterious effects on biodiversity can be avoided, and therefore it can only be done at low intensity. The same is true for bioenergy plantations. Plantations should be encouraged on existing agricultural lands and areas that have been heavily degraded, but substitution of current forests by bioenergy plantations should be avoided, as it both results in further emissions and negatively affects biodiversity.

3.5 Conclusion

Discussions of climate-change and forest policy often include suggestions that fires be suppressed to help reduce emissions. Forest fires contribute annually to important emissions of greenhouse gases, including 10-20% of annual global emissions of methane and nitrogen oxide, and there is little question that, in the short term, fire suppression enhances carbon storage. However, suppressing fires to protect either carbon or timber resources, although reducing emissions, may not be a sound alternative in the long term, or at least not for biodiversity. Many forest processes depend on natural fire regimes and for forests in many regions, their biological features developed in balance with a natural fire regime. The suppression of fires results in the accumulation of fuel, increasing the risk of future catastrophic fires. This in turn leads to cycles of unpredictable carbon storage and release. Whilst complete fire suppression is not desirable, non-natural fires could be controlled, and catastrophic fires can be prevented with mixed strategies allowing for small natural fires, while managing other stands with thinning or understory clearing.

Forestry intensification is often promoted because actively growing young trees are thought to sequester carbon more rapidly than old-growth forests. However this view has been challenged in recent years with increasing evidence that indicate a widespread increase in growth and net primary production in old growth forests across Europe (Spiecker et al., 1996) and in the neotropics (Malhi et al 2004). A recent study found that old growth forests in boreal and temperate zones of the Northern Hemisphere, amounting to 15% of the global forest cover, provide at least 10% of the global net ecosystem productivity

(Luyssaert et al., 2008). Additionally, from the point of view of maintaining biodiversity, replacement of natural old forests with plantations cannot be justified. Tree plantations, especially exotic monocultures, have less biodiversity than natural forests in the same regions (Helle and Mönkkönen, 1990; Noss & Cooperrider, 1994; Twedt et al., 1999; Magura et al., 2000; Humphrey et al., 2002) and alien species used in plantations have the risk of becoming invasive. Furthermore, due to their homogeneity, plantations are often more exposed to pest outbreaks than natural forests (Stephens et al., 2007) and are less resistant to disturbances such as fire, wind and snow avalanches as we have recently experienced in Europe.

The belief that young, intensively managed forests sequester more carbon than mature ones also ignores the tremendous releases of carbon that occur when forests are disturbed by logging activities (Schulze et al., 2000). Respiration from the decomposition of dead biomass in logged forests exceeds net primary production of the re-growth. Over several rotations of growth and harvest, the mean carbon pool of intensively managed forests is only about a third of that of primary forests (Cooper, 1983). Despite this, tree plantations on agricultural land and natural succession on abandoned lands could play a useful role in carbon sequestration (Schimel et al., 2000).

3.5.1 Strategies for maintaining biodiversity

Recommendable strategies of adaptation and mitigation in the forestry sector, when considering biodiversity Figure 3.3 summarises some of the main measures and their biodiversity impact.

- Conservation of existing primary forests and slowing down deforestation rates internationally to avoid emissions associated with forest degradation or clearing, especially in the tropics. Protection of forests should include representing forest types across environmental gradients, avoiding fragmentation; connectivity should be provided, particularly parallel to climatic gradients.
- Sequestration of carbon by increasing forest carbon absorption capacity by planting trees or facilitating the natural regeneration of forests, especially on marginal or agricultural land, and by making changes in forest management to increase biomass. Promote heterogeneous plantations with native, species mix and diverse gene pools.
- Forests are significant carbon sinks, but measures developed to increase the carbon sequestration should not negatively impact forest biological diversity.
- Favour low-intensity forestry with long-rotation times or retention of old-trees. Allow trees to grow larger and establish conservation set-asides within production forests.
- Favour continuous cover forestry instead of clear-cutting. Reduce damage to non-harvested trees and disturbance of forest soils during logging operations, to reduce CO_2 emissions and ecosystem

disturbance.

- Moderate fire control. The threat to biodiversity from lack of natural fire regimes in many forest types outweighs the potential advantages of fire suppression. Nonetheless, fires of anthropogenic origin and catastrophic large scale fires should be avoided. An optimal approach may include a combined strategy, in which many natural fires would be allowed to burn, but old growth would be protected from stand-replacing fires, and other stands would be managed by prescribed burning and understory thinning to reduce the risk of high-intensity fire.
- Avoid tree breeding (to increase forest production) as much as possible: it will result in a more limited gene pool. It is a debatable strategy from a biodiversity and climate change adaptation point of view.
- While in the long-term the production and use of renewable woody biomass can be of greater mitigation effect than increased forest carbon storage, the management for biomass should only be an option if deleterious effects on biodiversity can be avoided. The removal of wood debris has been identified as one of the main reasons for the decline and regional extinctions of many forest species. Thus a preferred alternative is to increase the amount of deadwood in managed forests

All these approaches increase the average long-term quantity of stored carbon and also tend to have beneficial effects on biodiversity, while enhancing resilience and resistance of the forest and promote the response of forest trees and associated species to environmental changes.

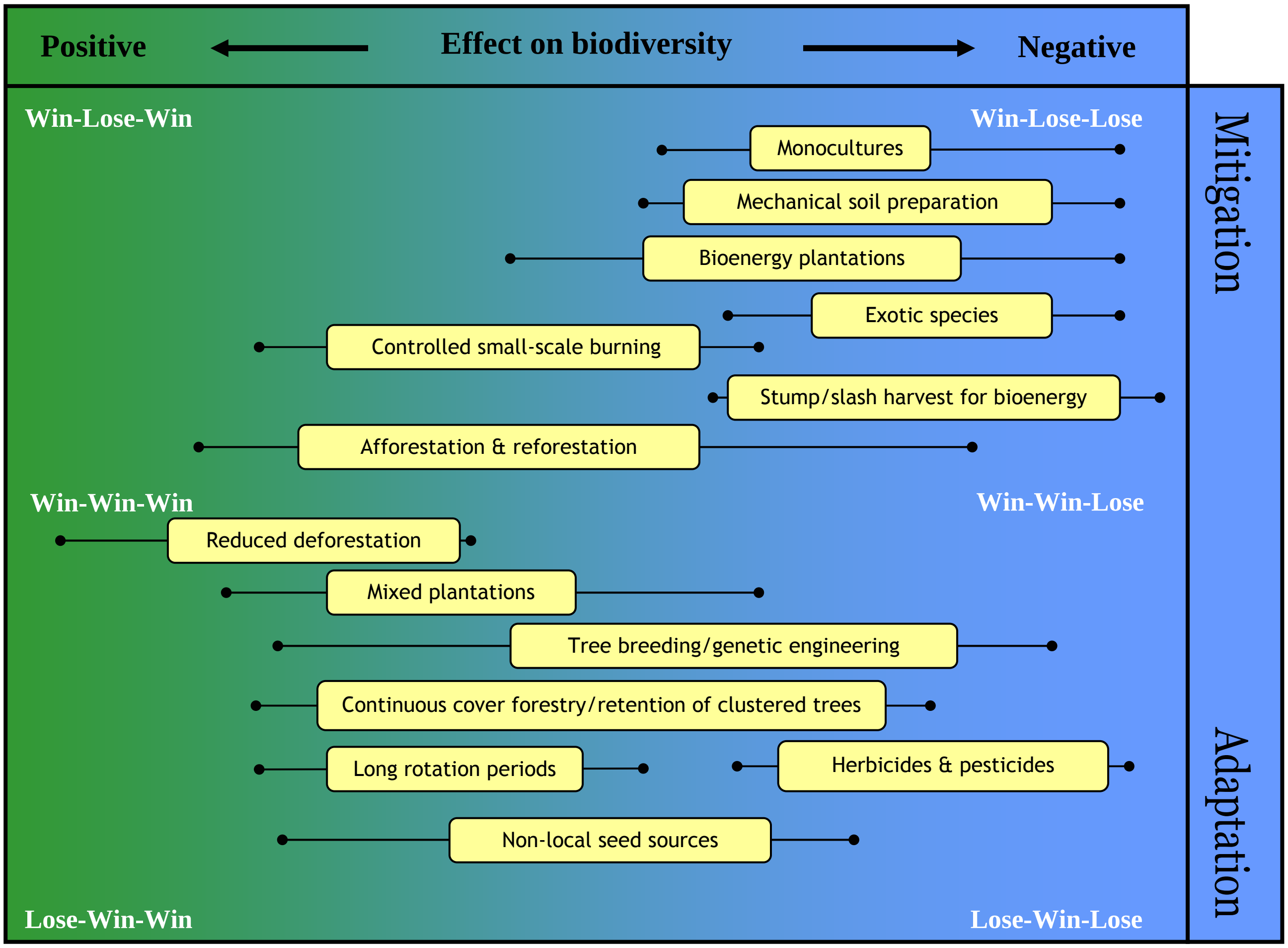

Figure 3.3: Known and potential relationships between mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on a literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts.

Forestry Mitigation or Adaptation Strategy	Biodiversity Impact		Habitats affected									Taxa affected					
	Impact under worst practice	Impact under best practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland and other wooded areas	Unvegetated or sparsely vegetated habitats	Agricultural, horticultural and domestic habitats	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants
Forest conservation	↗	↑			Ñ		Ñ		Ñ			Ñ	Ñ	Ñ	Ñ	Ñ	Ñ
Prevent deforestation	↗	↑			Ñ		Ñ		Ñ			Ñ	Ñ	Ñ	Ñ	Ñ	Ñ
Afforestation, general	↓	↗			Ñ	Ñ	Ñ	Ñ		Ñ	Ñ	Ñ	Ñ	Ñ		Ñ	Ñ
Bioenergy plantations	↓	↔			Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ		Ñ	Ñ
Reforestation, general	↘	↑			Ñ	Ñ	Ñ		Ñ				Ñ			Ñ	Ñ
Removal of shrubs prior to planting	↘	↓						Ñ	Ñ							Ñ	Ñ
Planting large tree-islands (as recruitment foci)	↑	↑					Ñ										
Artificial bat roosts for frugivorous bat species	↑	↑							Ñ			Ñ					
Use of shrubs as nurse plants	↑	↑							Ñ								Ñ
Mechanical soil preparation (blading)	↓	↘							Ñ			Ñ				Ñ	Ñ
Chemical soil preparation	↔	↗			Ñ				Ñ					Ñ		Ñ	Ñ
Non-local (but native) seed sources	↘	↗														Ñ	Ñ
Exotic species	↓	↘			Ñ				Ñ				Ñ			Ñ	Ñ
Genetically diverse assembly of seedlings	↗	↑														Ñ	Ñ
Monocultures	↓	↘			Ñ				Ñ			Ñ	Ñ	Ñ		Ñ	Ñ
Mixed stands of multiple species	↗	↑							Ñ								
Replacing old-growth forest	↓	↓			Ñ				Ñ			Ñ	Ñ	Ñ		Ñ	Ñ
Tree breeding/genetic engineering	↘	↗							Ñ								Ñ

Clearcutting	↓	↓							Ñ				Ñ			Ñ	Ñ
Selective harvesting	↘	↔							Ñ								
Continuous cover forestry	↔	↔							Ñ								
Sanitation cuts	↔	↔							Ñ								
Retention of clustered trees with intact undergrowth	↔	↗							Ñ								
Generation of coarse woody debries	↗	↑							Ñ								
Minimise soil disturbance	↗	↑							Ñ								
Minimise damage to non-harvested trees	↗	↑							Ñ						Ñ	Ñ	Ñ
Herbicide treatments	↘	↔							Ñ						Ñ	Ñ	Ñ
Fertilizer use	↘	↘			Ñ				Ñ								Ñ
Shorter rotation periods	↘	↘							Ñ							Ñ	Ñ
Longer rotation periods	↔	↗							Ñ								
Mixed species stocks	↗	↑							Ñ								
Thinning	↘	↔							Ñ							Ñ	Ñ
Undergrowth clearing	↓	↘							Ñ							Ñ	Ñ
Increase canopy height	↔	↗							Ñ								
Retention of large trees	↗	↗							Ñ								
Controlled small-scale burning	↗	↗							Ñ								
Use of wood in long-lifespan products	↔	↔															
Recycling of wood products	↔	↔															

Energy production/Slash harvest	↓	↘							Ñ							Ñ	Ñ
Energy production/Stump harvest	↓	↘							Ñ							Ñ	Ñ
Energy production/Harvest of whole trees	↓	↘							Ñ							Ñ	Ñ
Energy production/Chip production from production residues	↔	↔							Ñ								

3.5.2 Uncertainties and need for further research

Despite physiological and ecological experimentation, there is yet no clear understanding of how trees or forests will respond to climatic changes. Higher soil temperatures result in both enhanced soil respiration and enhanced soil mineralization and nutrient availability to the trees; increased precipitation is also associated with enhanced cloud cover; and higher air temperatures may lead to longer growing seasons but also to higher moisture stress. Biome transitions, following the expected expansion of forests over tundra at higher latitudes and over savannah in the tropics may result in a biome switching from being a carbon source to a sink or vice versa as climate change proceeds. Because of current limitations on our understanding with respect to acclimation of the physiological processes, the climatic constraints and feedbacks among these processes projections of carbon-sink strengths beyond a few decades are highly uncertain.

There have been significant advances in determining the carbon balance of forests, but there are still critical uncertainties remaining, particularly in the behaviour of soil carbon stocks. Globally, the long-term carbon balance is determined as much by the processes in the soil, as by changes in vegetation biomass. Carbon management programmes must incorporate considerations of soil carbon stocks but conventional forest management is mainly concerned with the volume and value of the stem wood product, and shows little regard for soil carbon stocks, which can be particularly vulnerable to management operations.

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4. Energy

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4.1 Introduction

The move towards to reducing GHG emissions in the energy sector has affected all types of energy, whether based on fossil fuels, renewable or radioactive sources (Sims et al., 2007). Clearly, some energy sources have a long-standing history of environmental degradation and even new, supposedly green sources, are not always as green as they claim (Pimentel and Patzek, 2006). As global energy demands continue to rise, the urgent need to reduce GH emissions and environmental impacts is paramount (IEA, 2006).

It is generally agreed that there is no single panacea to reducing GHG emissions from the energy sector; certainly many renewable energy sectors offer low or zero carbon potential but they often have either high environmental impacts (e.g., land-use, pollution, impact on species) or are difficult to implement because of high costs or poor public acceptance. In addition to these concerns, it is now becoming increasingly apparent that the adaptation capacity of energy sectors should also be considered. Arnell et al (2005) consider five main aspects for adaptation in the energy sector:

- The viability of renewable sources (e.g., water for hydropower).
- Energy-from-biomass schemes (climate change effects on plant growth).
- Availability of cooling water (for nuclear and coal power stations).
- Extraction of offshore oil and gas (disruption by extreme weather events).
- Physical infrastructure (e.g., power stations in low-lying areas like coastal zones).

This section examines the mitigation and adaptation options in the energy sector with the specific intention of highlighting known and potential impacts on biodiversity.

4.2 Energy supply sectors

4.2.1 Fossil fuels

Despite the growing need to curb the use of global fossil fuels (as the largest producer of GHGs), the production of oil, gas and coal for global energy supply is likely to remain in its dominant position (80% of world supply) until at least

2030 (IEA, 2006). However, even with the well-known environmental impacts of these fuel types, there is scope for reducing their GHG emissions; most measures aim to improve efficiency of either production or consumption (Huesemann, 2006; Moriarty and Honnery, 2008) or capture the carbon and sequester it in a range of possible media (Parson and Keith, 1998; Anderson and Newell, 2004; Azar et al., 2006; Hendriks, 2007; Sims et al., 2007; Strak and Wardencki, 2007; Bachu, 2008).

Carbon Capture and Storage (CCS) is being mooted by many as the long-term answer to reducing GHG emissions from this source (and others too) (Grimston et al., 2001). Although costly to implement, the process involves removing CO_2 from the power plant and storing it either in geological formations, ocean masses or in carbonate conversions (Grimston et al., 2001; Anderson and Newell, 2004; Hendriks, 2007). As yet, there are no major CCS systems installed in any major power plant but the technology is available and is being used in liquid natural gas plants (e.g., the Snøhvit field off the coast of Norway). It is worth noting that research and development into CCS is burgeoning and new technologies are emerging (Figueroa et al., 2008).

Effects on biodiversity

Improving fossil fuel efficiency, either through 'social efficiency' (Moriarty and Honnery, 2008) or technological efficiency (Ordorica-Garcia et al., 2006) are unlikely to have major negative environmental impacts and are more likely to be beneficial (e.g., lower water use in Integrated Gasification Combined Cycle plants: Liu et al., 2008). However, CCS techniques are still untested in many situations although they offer huge potential for CO_2 sequestration (Grimston et al., 2001). There are a number of aspects of CCS that need to be considered before their overall environmental and biodiversity impact is known:

- Capture site
- Type of energy source
- Type of Carbon capture system (post-combustion capture, pre-combustion capture, or oxy-combustion)
- Transport of carbon
- Location of carbon storage

These factors will influence the main environmental effects likely to arise from adopting CCS technology at existing sites.

- CCS systems are very energy-use intensive so will have a knock-on effect on the environmental impact of whatever fuel is used (e.g., coal from open-cast mines) (Anderson and Newell, 2004).
- While many pollutant emissions will also be reduced some will increase (e.g., ammonia) (Rao and Rubin, 2002)
- Land-use issues:
    - For example, will existing sites be converted to CCS (post-combustion is easily used in existing plants)? Or will all new sites be built (better suited to pre-combustion)? Either way there is an

    issue of land-use change that may affect biodiversity (Koornneef et al., 2008).
  - Additional effects on land use may be seen through the use of pipelines to transport carbon to the storage site or for longer distances the use of tankers may be adopted (Grimston et al., 2001; Gough and Shackley, 2005).
  - The terrestrial entry point for storage in geological formations (depleted or active oil and gas reservoirs, coal beds and deep aquifers).
- Effects of CO_2 leakage on ocean biodiversity have perhaps been the most discussed in the literature and increased levels of CO_2 may affect respiration on deep-sea mobile animals, calcification of coral reefs, trophic disturbance, metabolism, hypercapnia in acid-base regulation and ultimately mortality of fauna (Herzog et al., 1996; Tamburri et al., 2000; Chisholm et al., 2001; Seibel and Walsh, 2001; Huesemann et al., 2002; Seibel and Walsh, 2003; Carman et al., 2004; Kita and Ohsumi, 2004; Kurihara et al., 2004b; Kurihara et al., 2004a; Portner et al., 2004; Ishida et al., 2005; Thistle et al., 2005; Davies et al., 2007).

4.2.2 Nuclear

Nuclear power is viewed by many as having strong potential as a low-carbon energy source although, of course, it is highly controversial. After accounting for GHG emissions from uranium mining, issues of cost, international security and radioactive waste and environmental pollution, nuclear power is still seen by some as a possible solution to meeting our energy demands (Miller et al., 2006; Bickerstaff et al., 2008; Streimikiene, 2008).

Nuclear power generates 30% of Europe's energy needs from reactors in 15 EU countries (Schneider and Froggatt, 2008), most of which are from reactors in western Europe (France produced nearly half of the EU's nuclear energy). Although caution has been urged for the development of more nuclear power stations (Sustainable Development Commission, 2006), and despite the fact that nuclear power requires a finite fuel source (if it provided all the world's energy the uranium supply would last a maximum 30 years: Huesemann, 2006), the creation of new nuclear power plants in Europe seems likely (Miller et al., 2006) with France, Finland, Ukraine and Bulgaria and possibly Britain all building or planning new plants (European Nuclear Society, 2008). Such a major energy industry has a long and chequered past with regard to its environmental impacts – the further commissioning of new plants will possibly exacerbate many of the environmental problems.

Nuclear power is also one the most vulnerable energy sectors in terms of adaptation to climate change mainly due to: a) the large demands for cooling water (powers stations located near rivers maybe affected); and b) the impacts of sea-level rise, coastal erosion and storm surges for coastal power stations

(Arnell et al., 2005; Sustainable Development Commission, 2006). This may result in new plant being located inland next to large river systems.

Effects on biodiversity

The body of evidence showing the impact of nuclear power production on nearby and distant ecosystems is considerable. Environmental effects can be categorised in a number of ways, from the mining of uranium needed to fuel nuclear power stations to waste disposal of spent fuel. Any government strategy for nuclear power generation also has to take into account a risk assessment of the worst-case scenarios (Nedic et al., 2005); one needs to look no further at the huge body of research on the after-effects of the Chernobyl disaster (e.g., Davison et al., 1993; Tikhomirov and Shcheglov, 1994; Avery, 1996; Baker et al., 1996; Davydchuk, 1997; Ellegren et al., 1997; Smith et al., 1999; Baker and Chesser, 2000; Møller and Mousseau, 2006).

However, here we focus on the operational environmental effects of a nuclear power strategy. Nuclear power requires uranium to fuel the process which is mined in about 25 countries around the world (Romania, Czech Republic, France and Germany are the only countries in the EU but their collective production is quite small). There have been a number of studies focussing on the environmental impacts from the mining and milling of uranium (Meinrath et al., 2003; Hart, 2004; Carvalho et al., 2005; Mkandawire and Dudel, 2005; Carvalho et al., 2007). Most impacts result from the tailings as they account for the majority of the bulk of the minings as well as a very high percentage of the radioactivity from the ore (Hart, 2004). It is not only the ore radioactivity that presents problems but also the use of toxic chemicals (IAEA, 2002). A range of engineered barrier filters are normally installed to prevent the mining waste contaminating the environment although it is possible for nearby ecosystems to be affected. Past mines, with lower environmental standards have been shown to affect the ecosystem with either higher levels of radioactivity (Carvalho et al., 2007) or arsenic levels (Mkandawire and Dudel, 2005); current international standards and legislation offer better protection for the environment (IAEA, 2002).

Effects stemming from the operation of power plants are mainly three-fold: radioactivity, pollutants and water use.

- Nuclear power plants require large amounts of water for cooling processes but can kill fish larvae and juvenile and adult fish through entrainment (entrapment) in the water intake systems (Danila, 2000; Lorda et al., 2000; Turnpenny and Taylor, 2000; Henderson, 2004; Greenwood, 2008). Although fish mortality in this way does not normally have significant effects on fish populations, one study has raised concerns over the effects on conservation efforts for some species (Henderson, 2004).
- Water discharge from power plants can affect species through temperature differences and increased turbidity (cloudiness) (Snoeijs

and Prentice, 1989; Schroeter et al., 1993; Smythe and Sawyko, 2000; Thompson et al., 2000; Hadderingh and Jager, 2002; Taylor, 2006).
- Pollutants: the use of chlorine as an antifouling agent (Jenner et al., 1997) has been shown to affect the growth of mussels (Mytilus edulis) (Thompson et al., 2000).
- Escape of radionuclides into the environment (Kershaw et al., 1999; Roussel-Debet et al., 2006).

The final aspect to consider is the treatment of radioactive nuclear waste (Kumblad et al., 2003; Dowdall, 2005; Inman, 2005; Agüero et al., 2007). Due to the extremely long half-life of most radioactive materials the design and implementation of containment strategies is vitally important.

4.2.3 Solar

Solar energy is the main source of practically all our energy (Dukes, 2003) although the direct conversion of solar power provides less then 0.2% of total world energy supply (Sims et al., 2007). Despite this, the potential for solar power is immense and could potentially meet global demands quite easily with correct siting and efficient distribution (Philibert, 2004; Sims et al., 2007).

In Europe, the potential for solar power supply will mainly continue to be concentrated in the south (Alcamo, 2007), although globally Europe is not one of the prime areas for increasing solar power (Philibert, 2004). The direct use of solar energy is also quite varied in terms of design but can be summarised in two main forms - solar thermal energy and electricity generation (Trieb et al., 1997; Valera et al., 2003; Sims et al., 2007).

4.2.3.1 Solar thermal

Solar thermal energy can be harnessed in four forms – through water heating, space heating or cooling, process heat (solar pond) (Trieb et al., 1997) and for use in desalination plants (Caruso and Naviglio, 1999; García-Rodríguez, 2007). The first two forms are mainly small-scale and are usually applied to domestic house or small industrial operations; the second two are generally applied on a large, industrial scale.

4.2.3.2 Solar electricity generation

Two forms are commonly found: photovoltaics which can be used in domestic situations (Kalogirou, 2004a) to small-scale industrial (Tsoutsos et al., 2005; Huesemann, 2006; Lewis, 2007) and concentrated solar (Romero et al., 2002; Valera et al., 2003; Kalogirou, 2004b; Zarza et al., 2004) which uses a solar trough or parabolic dish to reflect and focus light to a tower to produce electricity; they require high levels of solar insolation.

Effects on biodiversity
The environmental effects resulting from the manufacture and operation of solar technologies are, in comparison to other energy sources, are quite minimal and designed and implement in the right way would have almost no impact (Trieb et al., 1997; Gitay et al., 2002; Tsoutsos et al., 2005). However, large-scale plants can compete for land-use with marginal or semi-natural lands, water use can be high which can have negative impacts on local ecosystems (Varho, 2002; Tsoutsos et al., 2005; Huesemann, 2006) and the disposal of (toxic) materials at the end of the life-cycle can pose problems (Fthenakis, 2000; Tsoutsos et al., 2005; Lewis, 2007; Mohr et al., 2007).

Certainly the large-scale development of solar power plants will use a lot of land and water (this may be a particular problem in areas with water shortage issues) (Huesemann, 2006) – but with comparison to other energy production systems, solar power offers a comparatively small ecological footprint (Pimentel et al., 1994; Asif and Muneer, 2007). Assuming that the highest solar insolation areas are utilised, the major issue will become transfer and distribution of energy to demand areas - this may result in habitat loss or disturbance.

4.2.4 Wind power

Wind generated power has been utilised for centuries although its large-scale commercial application is only about thirty years old. Wind power does not account for a large proportion of energy supply in Europe, even in countries with an established usage (e.g., wind provides 18.5% of Denmark’s energy supply, the highest per capita in the world (Sims et al., 2007)). However, there is major potential to increase the contribution of wind power to European energy supply (Archer and Jacobson, 2005; Sims et al., 2007) although in some parts a saturation point is already being reached (Fairless, 2007).

Wind energy is commonly harnessed in large wind farms where each turbine can produce up to 5MW (Keith et al., 2004; Archer and Jacobson, 2005; Huesemann, 2006; Sims et al., 2007; Yang, 2007) but smaller turbines are also found in urban areas (Peel and Lloyd, 2007) and even on domestic housing.

Although there is a great deal of uncertainty regarding the effects of climate change on the wind resource for Europe, it is predicted that wind energy will increase over northern European and the Atlantic zone (Pryor et al., 2005).

Effects on biodiversity
The development of wind farms has been hampered by a rigorous conservation movement which have opposed many wind energy projects. There have been long-standing concerns over the impacts on wildlife, particularly birds (Langston and Pullan, 2003; Barrios and Rodriguez, 2004; Garthe and Huppop, 2004; Drewitt and Langston, 2006; Huppop et al., 2006; Whitfield and Madders,

2006; Larsen and Guillemette, 2007; Marris and Fairless, 2007) and bats (National Research Academy, 2007; Baerwald et al, 2008; Horn et al., 2008), but the impacts of wind farms can be more widespread - perhaps the public's concern is mostly voiced through fears over blighting landscapes. Although there is not an extensive collection of data relating to the ecological impacts of wind farms, the synthesis of existing data suggests that the conservation movement has very real concerns for biodiversity loss:

- Habitat loss (Langston and Pullan, 2003; Drewitt and Langston, 2006) and fragmentation. In Europe, habitat impacts are reckoned to larger than those related to collisions (Gill et al., 1996). Disturbance effects have been shown to range from 75 m to 800 m from turbines for some birds (see National Research Academy, 2007 and references therein).
- Bird and bat collision, (Langston and Pullan, 2003; Barrios and Rodriguez, 2004; Drewitt and Langston, 2006; Huppop et al., 2006; Whitfield and Madders, 2006; Baerwald et al, 2008), with studies in the US showing that about 75% of bird the fatalities are passerines (National Research Academy, 2007). Bird loss through turbines, however, is insignificant compared to losses from cars, house-window collision and domestic cats (Marris and Fairless, 2007).
- Barrier to bird migration (Barrios and Rodriguez, 2004; Garthe and Huppop, 2004; Drewitt and Langston, 2006; Huppop et al., 2006)
- Disturbance of bird and other taxa (Langston and Pullan, 2003; Larsen and Guillemette, 2007)
- Damage from construction – offshore pollution (Langston and Pullan, 2003; Gill, 2005).

The ecological impacts are complex and can vary with temporal and spatial scale (National Research Academy, 2007). They are thought to depend upon a number of factors, including location (areas where species congregate – for feeding, nesting or flying should be avoided), turbine size, design, season, weather, ecosystem type and species (National Research Academy, 2007). Studies in the US, for example, suggest that for bats the highest fatality rates occur for migratory species, episodically in late summer/early autumn, under low wind conditions (<6m per second) after passing fronts (National Research Academy, 2007). For birds, raptors appear to be the most vulnerable to collision and yet they are seldom the most abundant bird group present; however this could be a result of the relatively large raptors body size which are more easily found (compared to, say, passerines) (National Research Academy, 2007). Generally, fatalities are positively correlated with bird abundance.

In summary, despite the list of known and possible effects on biodiversity, the overall impacts are quite low compared to other energy sectors (Marris and Fairless, 2007).

4.2.5 Hydropower

The range of designs for implementing the kinetic or potential energy of water is quite considerable but most are based on either tidal, wave or hydroelectric systems. Hydropower has been harnessed throughout the world and is the largest current renewable energy sector (Sims et al., 2007).

Adaptation issues are more important here as predicted changes in sea level and water supply are likely to affect hydro schemes (Arnell and Hulme, 2000; Arnell et al., 2005; Lehner et al., 2005). Hydro resources are likely to decrease in southern Europe but increase in northern Europe (Alcamo, 2007); the overall hydro resource will decline though.

4.2.5.1 Tidal

Tidal power come from two forms: tidal stream which uses the kinetic energy of water moving through turbines; and, barrages which uses the difference in height between low and high tides (potential energy). Perhaps the most famous barrage tidal power plant is on the River Rance in France (Charlier, 2007), although there are a number of plans to create new barrage schemes, the available sites globally are very limited. Tidal stream power is generally a lot more environmentally benign than barrage systems.

Effects on biodiversity

Tidal schemes can have multitude of effects on biodiversity:

- Changes in flow (Sustainable Development, 2007).
- Fish mortality from turbines (Sustainable Development, 2007).
- Changes to saltmarsh (Clark, 2006) (Sustainable Development, 2007).
- Changes to intertidal areas (Little and Mettam, 1994; Clark, 2006; Sustainable Development, 2007).
- Changes in fish migratory patterns (Little and Mettam, 1994; Sustainable Development, 2007).
- Turbidity and sediment movement (Sustainable Development Commission, 2007).
- Salinity (Charlier, 2007).

4.2.5.2 Wave

Although the contribution of wave energy is not expected to be significant in the future due to the large economic costs involved and the complications arising from siting wave-machines (e.g., avoidance of shipping lanes, marine reserves, fishing areas) (Falnes and Lovseth, 1991; Sims et al., 2007), it is still considered a viable option by some and various projects in Europe are being pursued (e.g., off the coast of Cornwall in England: Millar et al., 2007). To date, there are no known detrimental biodiversity effects (possibly reflecting its early development stage).

4.2.5.3 Hydroelectric

Hydroelectric power is commonplace in many European countries and ranges from 0.1% of total electricity generation in Denmark to 99.4% in Norway (Lehner et al., 2005; Bakis, 2007). Most of the potential of European hydropower has already been tapped (Gitay et al., 2002; Secretariat of the Convention on Biological Diversity, 2003; Sims et al., 2007) although there are still opportunities for small-scale hydro schemes in many countries. The impacts on biodiversity vary greatly depending on the scale, design and the location of the project. The two main types of hydroelectric are small-scale (usually up to 10MW) which includes run-of-the-river designs (no impoundment of water) and large-scale (10MW up to 20,000+ MW).

4.2.5.3.1 Large-scale hydroelectric

Large-scale hydroelectric schemes have, without question, caused the most damage to ecosystems of any hydropower type (and most other renewable energy sources) (Secretariat of the Convention on Biological Diversity, 2003). In Europe, they have been a longstanding scourge of conservationists, and in recent years, particularly in Portugal, they still dominate the environment agenda (Teixeira, 2002; Freitas and Horta, 2003).

Effects on biodiversity

The impact on local and regional biodiversity can be considerable but will depend upon the original conservation value of the location and the size of the power plant. Known impacts of large hydroelectric schemes are:

1. Upstream impacts
   i. Destruction of semi-natural and natural habitats by damming and creation of reservoirs (Baxter, 1977; Craig, 2000; Freitas and Horta, 2003).
   ii. Conversion of lotic (flowing) to lentic (still) aquatic habitat and the consequential effects on specialist species (Baxter, 1977; Craig, 2000).
   iii. Landscape fragmentation effect – e.g., migration of terrestrial animals may be affected (McAllister et al., 2000; McCartney et al., 2000; Wu et al., 2003; Bratrich et al., 2004; de Almeida et al., 2005; Reidy Liermann, 2007; Lévèque et al., 2008).
   iv. Increase in mercury – the creation of reservoirs sometimes results in higher levels of mercury arising from bacterial transformation of normal mercury present in soils to methyl mercury which can have severe effects on fish and even birds (Craig, 2000; McAllister et al., 2000; McCartney et al., 2000; Nilsson and Berggren, 2000; Mailman et al., 2006).
2. Downstream impacts
   i. Barrier to fish migration – e.g., salmon reaching spawning grounds (Auer, 1996; Zhong and Power, 1996; Bernacsek, 2000; Larinier,

2000; McAllister et al., 2000; Nilsson and Berggren, 2000; Bratrich et al., 2004; Reidy Liermann, 2007; Thorstad et al., 2007).

ii. Reduction is sediments resulting in river scouring (Baxter, 1977; Allan and Flecker, 1993; McAllister et al., 2000; Nilsson and Berggren, 2000; Bratrich et al., 2004; de Almeida et al., 2005; Baisre and Arboleya, 2006; Poff et al., 2007; Reidy Liermann, 2007).

iii. Mortality of fish species through turbines (Baxter, 1977; Bizer, 2000; Larinier, 2000; McAllister et al., 2000).

iv. Altering hydrological flows which leads to the homogenization of rivers resulting in lower river biodiversity (McAllister et al., 2000; Seddon, 2000; Moyle and Mount, 2007; Poff et al., 2007; Reidy Liermann, 2007).

v. Loss of nutrient movement (Baxter, 1977; Bernacsek, 2000; McAllister et al., 2000; McCartney et al., 2000; Nilsson and Berggren, 2000; Baisre and Arboleya, 2006).

vi. Reduction or changes in turbidity to which species have been adapted (Bernacsek, 2000; McAllister et al., 2000; McCartney et al., 2000).

vii. Large organic debris filtered by dam which removes important nutrient and habitat source for downstream biota (McAllister et al., 2000).

viii. Estuarine impacts following from loss of nutrient transport due to damming (Bernacsek, 2000; McAllister et al., 2000; Vorosmarty et al., 2003; Syvitski et al., 2005; Baisre and Arboleya, 2006; Reidy Liermann, 2007; Syvitski and Milliman, 2007) and increase salinity due to loss of freshwater flow (Craig, 2000).

4.2.5.3.2 Small-scale hydroelectric

Most small-scale hydro schemes are, in fact, run-of-the-river designs which means they do not require reservoirs (Paish, 2002) (although there are small hydropower schemes that involve dams also). Typically, small-hydropower schemes are less than 10MW (micro-hydro is normally below 100 kW) and offer far greater potential for tapping into previously unused rivers (Kaldellis et al., 2005; Montes et al., 2005; Anagnostopoulos and Papantonis, 2007; Punys and Pelikan, 2007; Sims et al., 2007; Kaldellis, 2008).

Effects on biodiversity

Small-scale hydro schemes are far less detrimental to river and landscape biodiversity than large-scale hydro schemes (Bakis, 2007); however, that is not to say that there are no impacts:

- For *non* run-of-the-river systems fish passage can still be a problem (Nilsson and Berggren, 2000) although it can vary greatly depending upon the design of the dam (e.g., if fish ladders or lifts have been included) (Santos et al., 2006).
- Other important impacts include fish death from turbines, and minor damage to bank side vegetation from the construction, road building etc (Pinho et al., 2007).

- For small-scale impoundment schemes the impacts mentioned above for large-scale designs can sometimes also be a problem although to a lesser degree. The compounding effect of more than one small-scale schemes in the same river system may also reduce overall river biodiversity (Nilsson and Jansson, 1995).

4.2.6 Geothermal

Geothermal energy currently supplies 0.4% of the global energy use and it is often mooted as one the cleanest renewable energy sources (Sims et al., 2007). Many geothermal resources are already being utilized, despite this geothermal is expected to contribute more to European and global energy (IEA, 2006; EurObserv'ER, 2007; Martinot et al., 2007). Geothermal also has the advantage of all-day and all-season availability (Hurter and Schellschmidt, 2003).

Geothermal can be used for heat and electricity production but generally this sector is divided into two types depending on their energy content: electrical generation requires temperatures greater than 150°C, anything lower is suitable for direct heat uses (unless binary fluids cycles are used) (Mock et al., 1997; EurObserv'ER, 2007; Sims et al., 2007). Sixteen out of the EU25 countries already use low energy methods (EurObserv'ER, 2007).

Geothermal also has the advantage of being fairly resilient to climate change; in terms of geothermal adaptation capacity there is little that can affect most geothermal plants.

Effects on biodiversity
A range of environmental assessments of geothermal plants have been made over the years although generally, their impacts are insignificant compared to most other energy sources. The known impacts are outlined below:

- Land subsidence (Rybach, 2003; Arnorsson, 2004).
- Increased incidence of seismic activity (Rybach, 2003; Arnorsson, 2004).
- Chemical pollution of waterways from arsenic, boron, cadmium, and lead, iron, zinc and mercury can occur (Axtmann, 1975; Robertson et al., 1977; Kristmannsdóttir and Ármannsson, 2003; Baba and Ármannsson, 2006) although can largely be avoided by re-injection (Axtmann, 1975; Kaygusuz and Kaygusuz, 2004; Baba and Ármannsson, 2006).
- Atmospheric pollutants like hydrogen sulfides (Kristmannsdóttir and Ármannsson, 2003; Rybach, 2003) which contribute to acid rain.
- Land use and landscape changes from construction, drilling, road building, waste disposal (Rybach, 2003; Arnorsson, 2004).
- Soil erosion (Arnorsson, 2004)
- Noise disturbance to wildlife like nesting birds (Kristmannsdóttir and Ármannsson, 2003; Rybach, 2003).

- Drying out of hot springs (Kristmannsdóttir and Ármannsson, 2003; Arnorsson, 2004) which will affect thermophilic vegetation such as algal mats, thermophilic plants and bacteria (Kristmannsdóttir and Ármannsson, 2003).

Despite this list, generally the environmental impacts of geothermal power generation are minor (certainly in comparison to most other energy sources) or easily controlled and mitigated (Mock et al., 1997; Rybach, 2003). One direct comparison with hydroelectric energy found that geothermal had a lower impact on a range of environmental and ecological criteria (Thórhallsdóttir, 2007).

4.2.7 Bioenergy

Much of the analysis and discussion of this sector has been covered in the chapters on agriculture and forestry. Here we just discuss renewable solid municipal waste for energy production through combustion in incineration plants (Baggio et al., 2008). The production of energy from incineration in the EU reached 5.3 million tonnes of oil equivalent in 2006 and is expected to increase as industry and local authorities react to increased fossil fuel prices (EurObserv'ER, 2007).

Effects on biodiversity
Overall, the negative environmental effects of incineration of municipal waste are small compared to other energy sectors; most effects result from atmospheric pollutants but nowadays most new plants will have filters to control this (Baggio et al., 2008).

4.3 Conclusion

The impacts of most energy sources on biodiversity can, to a certain extent, be mitigated through careful design and implementation although often at prohibitively expensive costs. Ultimately, the adoption or promotion of new energy sectors will depend upon a myriad of socio-political factors and biodiversity conservation may not necessarily be the most important deciding criterion. However, knowledge of current and potentials impacts is an important part of the planning process and may help to sway the promotion of a more biodiversity-friendly option. A summary of the mitigation potential, adaptation issues, biodiversity impacts and energy potential of each energy sector is shown in Table 1. The second table provides greater detail on the effects that each energy sector has on habitats and species groups. The Biodiversity impact is demonstrated using the following symbols:

The interrelationship between mitigation, adaptation and biodiversity is of crucial importance for society; the loss of biodiversity due to any mitigation or adaptation effort may well prove to compound a loss in vital ecosystem services. Indeed, biodiversity may by itself confer adaptation capacity in a number of other sectors (e.g., agriculture). The figure below outlines these interrelationships – it is clearly apparent that with the exception of large-scale hydro power schemes, all the energy sources have little adaptation potential.

There is still much research required to fully understand not only the mitigation potential of some of these energy sources (e.g., CCS), but also their impact on biodiversity. For example, whilst we are aware of how wind farms can impact on bat and bird species we are still unclear how this may affect whole populations if wind farms are promoted more fully. Similarly, wave power, a relatively new and barely adopted source, has little or no information on its effects on biodiversity.

Table 4.1: Summary of energy sectors

Energy sector		Adaptation concerns		Mitigation	Biodiversity impact	Energy potential
		North	South			
Nuclear	Nuclear	1. Large water demands will be affected by reduction in river flow 2. Low lying sites are vulnerable to floods, extreme sea events etc		Good	Site specific. Medium to very High losses possible. Nuclear disaster would be extremely bad for biodiversity on a large scale.	High, but costly and concerns over safety. Uranium is also a finite resource.
Fossil fuel energy	Coal		As above	Poor	Medium to High depending on location and if CCS is adopted	High
	Oil	Increase incidence of sea storms		Poor	As above	High
	Gas	As above	Extreme weather events may affect ocean pipelines	Medium	As above	High
Renewable	Solar thermal		Will improve	Good	Low	Localised
	Solar electric		As above	Good	Low	Medium
	Wind farms			Good	Low	Low to Medium

	Small-scale wind			Good	Low	Localised
	Large dams for hydropower	Increase in water inflow	Reduction in water inflow	Medium (concerns over construction materials	High	Medium
	Small hydro	Increase in water inflow	Reduction in water inflow	Good	Low to Medium	Low
	Run-of-the-river	Increase in water inflow	Reduction in water inflow	Good	Low	Low
	Tidal barrage			Poor to Medium (construction materials)	Medium to High	Medium to High
	Stream tidal			Good	Medium	Low
	Wave			Good	Low	Medium
	Geothermal		None	Some CO_2 emission but generally very high potential	Localised if any; most likely is noise disturbance	Low
	Annual crop biofuel	Most crops should have increased growth	Some crops may have reduced yields under climate	Medium, need energy to grow crops	Low to High depending on crop and location	Low
	Perennial crops		Will cope better in drought than annual crops	Medium	Medium to Low	Low
	Municipal waste			Good	Low	Low

The interrelationship between mitigation, adaptation and biodiversity is of crucial importance for society; the loss of biodiversity due to any mitigation or adaptation effort may well prove to compound a loss in vital ecosystem services. Indeed, biodiversity may by itself confer adaptation capacity in a number of other sectors (e.g., agriculture). The figure below outlines these interrelationships – it is clearly apparent that with the exception of large-scale hydro power schemes, all the energy sources have little adaptation potential.

There is still much research required to fully understand not only the mitigation potential of some of these energy sources (e.g., CCS), but also their impact on biodiversity. For example, whilst we are aware of how wind farms can impact on bat and bird species we are still unclear how this may affect whole populations if wind farms are promoted more fully. Similarly, wave power, a relatively new and barely adopted source, has little or no information on its effects on biodiversity.

The Biodiversity impact is demonstrated using the following symbols:

- ↑ Highly beneficial for biodiversity,
- ↗ Moderately beneficial for biodiversity,
- ↔ No known effect on biodiversity,
- ↘ Moderately detrimental for biodiversity,
- ↓ Highly detrimental for biodiversity,
- ? Indicates uncertainty over outcome due to lack of reliable data

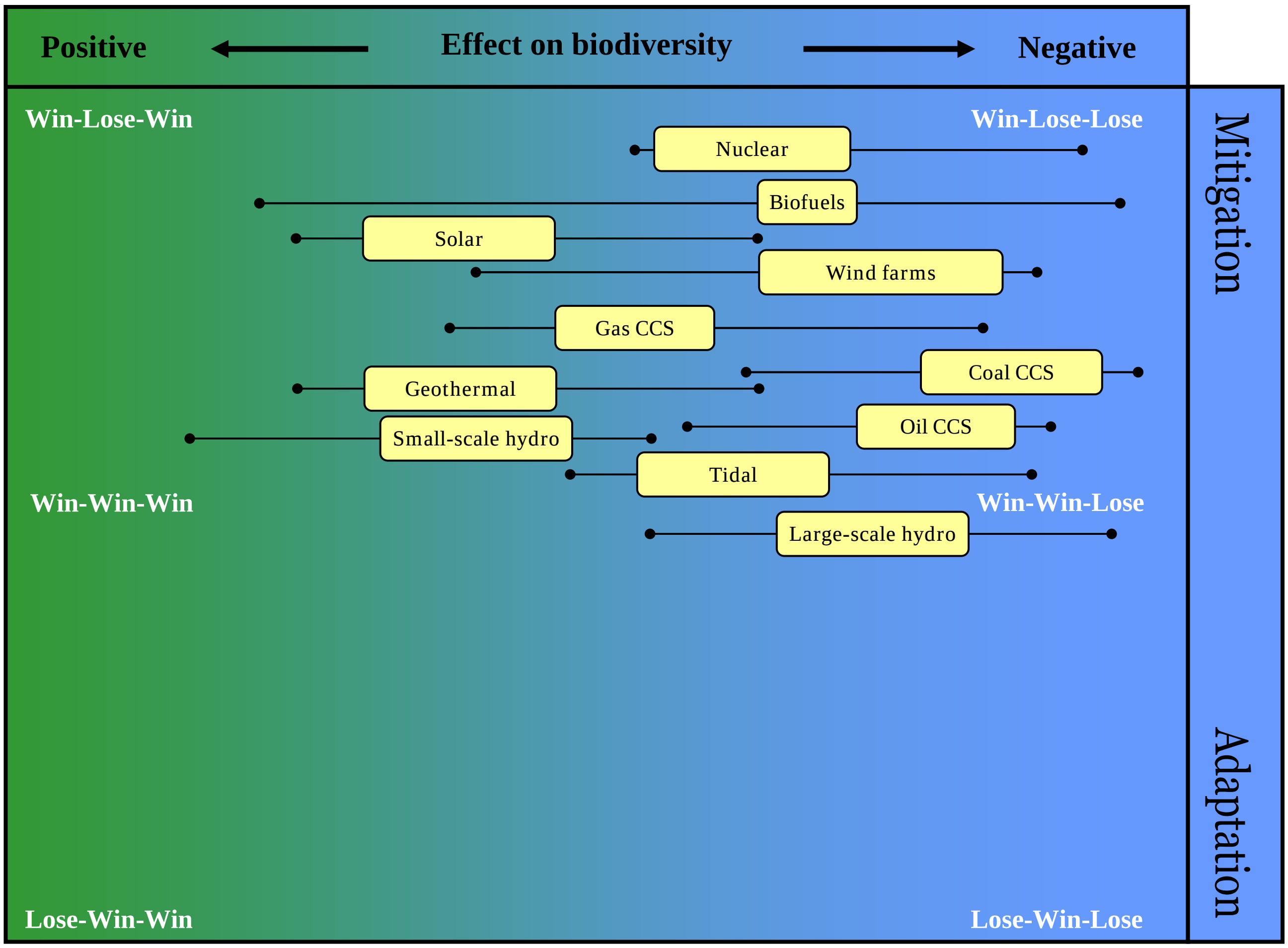

Figure 4.1: Known and potential relationships between mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on a literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts.

Table 4.2: Biodiversity impacts of different energy sectors

Energy Mitigation or Adaptation Strategy	Biodiversity Impact		Habitats affected									Taxa affected					
	Impact under worst practice	Impact under best practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland and other wooded areas	Unvegetated or sparsely vegetated habitats	Agricultural, horticultural and domestic habitats	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants
Nuclear	↓	↔	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ
Coal	↓	↔			Ñ	Ñ	Ñ	Ñ	Ñ	Ñ					Ñ		Ñ
Oil	↓	↔															
Gas	↓	↔	Ñ														
Solar thermal	↔	↔					Ñ			Ñ					Ñ		
Solar electric	↔	↔					Ñ								Ñ		
Wind farm	↘	↔									Ñ	Ñ	Ñ				
Small-scale wind	↘	↔									Ñ	Ñ	Ñ				
Large hydro	↓	↘			Ñ		Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ	Ñ
Small hydro	↘	↔			Ñ						Ñ				Ñ		
Run-of-the-river	↔	↔			Ñ										Ñ		
Tidal barrage	↓	↘	Ñ	Ñ		Ñ							Ñ	Ñ	Ñ	Ñ	Ñ
Stream tidal	↘	↔													Ñ		
Wave	↔	↔	Ñ	Ñ													
Geothermal	↘	↔															
Annual crop biofuel	↓	↗							Ñ		Ñ	Ñ	Ñ			Ñ	Ñ

Perennial crop biofuel	↘	↔									Ñ	Ñ	Ñ			Ñ	Ñ
Municipal waste biofuel	↘	↔								Ñ	Ñ						

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5. Built environment

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5.1 Introduction

This chapter covers climate change mitigation and adaptation strategies and measures, which may be put into effect within urban areas and in connection with built infrastructure such as roads, rail, power supply, etc. Potential impacts upon biodiversity resulting from introduction of the main forms of mitigation are considered (reduction of energy use, energy-efficiency measures, a switch away from fossil-fuels, and carbon sequestration), then any consequences of measures designed to assist in adapting to unavoidable climate change are reviewed. In addition to planned or policy-based measures, there will also be “autonomous” changes, such as increased use of air-conditioning, which will have impacts also- these are indicated.

There are many areas of interaction between construction and the built environment as well as other sectors, particularly transport, energy and water use. The location and design of housing, for example, has a significant impact upon the transport flows generated and how much energy is used for supply of services; consequently there will be some overlap with other chapters of this report. Moreover, some of the measures mentioned provide a route to both mitigation and adaptation (e.g. green roofs), but to avoid repetition they are discussed in the more relevant section.

Mitigation and adaptation in the built environment must address on the one hand the existing built stock and on the other, the planning, design and construction of new buildings and infrastructure. Some of the options involved may apply only to plans for future construction, but the proportion of new build housing is but a very small proportion of the total housing stock, e.g. the UK annual new build is estimated to be 1% of total stock (2007). Adaptation options for existing stock – requiring the introduction of innovative technology to existing and old buildings - are relatively restricted and may involve retro-fitting or replacement (see below, section 5.3.1). Boardman (2007) proposes that, as so much UK housing stock exists already and (she argues) a significant proportion can never be retro-fitted to meet 60% CO_2 reduction targets, it needs to be demolished by 2040. Such measures would entail significant impacts for biodiversity in disposing of construction waste and sourcing new materials. Lowe (2007) also discusses likely replacement rates for buildings and infrastructure, and consequences for emissions. Section 5.5 reviews synergies and possible conflicts. Most of the literature relates to new construction but there has recently been more interest in refurbishment and retro-fitting, e.g.

CABE (2007).

It is recognised (e.g. Watkiss, 2005) that some forms of adaptation may be "maladaptation", i.e. adaptation which entails inefficient use of resources compared to other options, either in economic or other terms, which exacerbates emissions, is ineffective or displaces vulnerability to climate change from one sector or region to another. Within each sub-section below both "opportunities" and "threats" have been considered on the basis of the available literature (and wider discussion). The built environment sector - encompassing built areas, construction and spatial planning - is a focus of many pressures on the environment (demographic change, economic activity, consumption and waste production, etc.) and all these pressures interact with the further pressure that is climate change. Watkiss (2007) has reviewed the costs of inaction and adaptation with respect to climate change.

The following review is based principally on published academic research papers which relate to climate change mitigation and adaptation-related impacts upon biodiversity. In addition to these, a good deal of policy guidance has been produced in the past few years, for example the findings of EU research projects: Piper (2006), BRANCH (2007), and ESPACE (2007) as well as Shaw et al. (2007) and SEECP (2005), all of which make recommendations on urban development under conditions of climate change.

5.2 Biodiversity in urban areas

Mitchell et al. (2007) have reviewed likely direct and indirect impacts of sectoral policies in urban areas upon biodiversity, under projected levels of climate change. This report concluded that there is a "medium risk" of direct impacts in terrestrial and freshwater habitats in UK built areas, with a relatively low impact discerned in estuarial and coastal habitats (p. 67) - though this would be influenced by managed realignment and sea level rise. This study's examination of indirect effects concerned measures such as assessment procedures (SEA, sustainability assessments, Appropriate Assessment), sustainable urban drainage and measures such as species change and building design. The study concluded that opportunities for biodiversity are offered by these approaches.

Grimm et al. (2008) have discussed the ecology of urban areas/cities and emphasize the consumption, population, waste and water-related drivers that affect biodiversity, amongst other elements. Urbanization leads to increased patch fragmentation with adverse impacts for biodiversity. Grimm et al. also note that:

> "The "edge" of the city expands into surrounding rural landscape, inducing changes in soils, built structures, markets, and informal human settlements, all of which exert pressure on fringe ecosystems".

Grimm et al. (2008) describe how the urban socio-ecosystem both drives and responds to environmental change, affecting biodiversity, biogeochemical cycles (through wastes affecting air and water transport) and the hydrological cycle at the level of the urban heat island, the regional and, ultimately, the planet. Cities are point sources of CO_2 and GHG; nevertheless, they also can be seen as potential "hotspots" for solutions to these problems (Grimm et al., 2008).

Biodiversity is strongly affected by the level of modification of the environment and the level of human activity (McKinney, 2006); whilst in some circumstances species diversity (including non-native species) may be greater in urban than in rural areas (Henderson, 2003). Pickett et al., (2008) describe the distribution of urban biodiversity as heterogeneous and individualistic and note that both exotic and native species have functional value in urban systems. Species diversity at a range of urban sites has been compared by Blair (1996 - birds) and Blair and Launer (1997 - butterflies). These researchers found that the proportion of exotic/invading species rises with the degree of disturbance from the natural state. Species richness, diversity, and bird and butterfly biomass peaked at moderately disturbed sites. Parris and Hazell (2005) note that human activity affects urban microclimates and anthropogenic climate change is likely to complicate further the task of conserving biological diversity in urban environments (see also Shochat et al., 2006). In terms of wildlife density rather than biodiversity, Tratalos et al., (2007) note a negative correlation between bird densities and housing densities.

5.3 Mitigation strategies and measures

5.3.1 Reduction of energy use

As part of the UK's Sustaining Knowledge for Climate Change research programme, it has been estimated that globally, buildings use an estimated 40% of primary energy (rising to 46% in the UK) (Davies, 2007). A reduction of demand for energy might lead to fewer negative impacts on biodiversity through conventional energy generation, either directly (e.g., reduced loss of estuarine sites to power generation and less use of cooling waters at existing power stations), or indirectly, where resource use is reduced and less energy is required to process or supply resources (e.g. energy for pumping water to households and manufacturers).

There are many ways in which energy use might be reduced within the built environment, associated with transport of people and goods within and between urban areas, the energy-efficiency of the buildings they use and the appliances and machines within them (see Table 5.1). Some of these options apply only to situations of newly developed areas, or require the wholesale demolition, redesign and replacement of urban areas. Note that some of these options may give rise to varying effects– see section 5.5: Conflicts, synergies and conclusions.

5.3.1.1 Modal shift

To reduce energy use in transport associated with the built environment measures must cover the movement of both people and goods. This may mean a modal shift from vehicles to walking or cycling for shorter distances, and a shift to public transport (bus, train) for both goods and people for longer distances. Benefits to urban biodiversity should accrue from reduced disturbance and from more biodiversity-friendly routes and pathways, where available.

Whilst a move into public transport would cut overall emissions, any construction of new public transport links (rail, road or new footpaths/cyclepaths built without due attention to biodiversity) would be very likely to increase habitat fragmentation and disturbance in the short term, with impacts for biodiversity (see, for example, roads - Coffin, 2007). Cuperus et al. (2002) have examined first-generation compensation plans for Dutch highway projects where the aim is to counterbalance the adverse ecological impacts of large-scale development projects - the obstacles to progress on this included increasing demand for land for development (climate change was not part of this analysis). A German development compensation system is summarized in section 5.4.1 below.

Table 0.1: Measures for energy use reduction, built environment sector

Type of option	Measures
Transport related	Modal shift: from motorized vehicle to walking and cycling and from private to public transport Urban intensification and reduction of urban sprawl, to reduce the need to travel by vehicle within the urban area or between urban areas (also affected by availability of service provision, e.g. hospitals, schools)
Replacement of built stock	Demolition of energy-inefficient buildings and their replacement with low- or zero-carbon buildings
Building improvement, refurbishment and retro-fit	Insulation / cooling / shading options
Building design for energy saving	Thermal mass, passive ventilation, orientation, roofing, fenestration, etc.

5.3.1.2 Urban intensification and reduction of urban sprawl

Two strategic responses to climate change are in apparent conflict here - on the one hand the design of more compact towns and cities might mean a lesser requirement for vehicle transport (McEvoy et al., 2006; Boardman, 2007; Schiller, 2007; McEvoy, 2006). On the other hand, intensification might mean fewer opportunities for biodiversity (Bosher et al., 2007) as well as potential impacts on urban drainage and lower infiltration (McEvoy, 2006), which would also impact biodiversity. McEvoy et al. (2006) also suggest that denser, hotter "heat island" cities may encourage their populations to use more energy on transport, escaping the city for recreational visits. See Figure 5.1 for a sketch of the likely significance building density has on temperatures.

Urban intensification, for example, may be achieved by regenerating under-used commercial areas near city-centres (warehouses, etc.), building on suburban gardens or preventing urban sprawl through planning controls. The reduction of urban sprawl is discussed by Ludlow (2007).

5.3.1.3 Energy-efficiency measures

This is taken to mean more energy efficient appliances (for energy efficient buildings, see below). These measures will include low-energy light bulbs, waste reduction (Mayor of London, 2007) and efficient domestic water using machines, given the high energy use involved in water transport. The CEC's Action Plan for Energy Efficiency: Realising the Potential, is supported by a range of directives and regulations which should improve energy efficiency in energy-using products, buildings and services. These include the Eco-Design Directive, the Energy Star Regulation, the Labelling Directive and its implementing Directives, the Directive on Energy End-Use Efficiency and Energy Services and the Energy Performance of Buildings Directive (CEC, 2006).

Low energy street-lighting (or reduction in street-lighting) are further measures for energy reduction in the built-environment. The benefits for wildlife here are in terms not only of reduced emissions and better air quality, but also reduced night-time disturbance.

Similarly, energy use may be reduced indirectly, where greater efficiency in the use of other resources (e.g. water) means less energy is required to transport or process the resource.

5.3.1.4 Building design for energy saving

Factors in building design identified as reducing energy requirement for both heating and cooling and, consequently, emissions reduction, have been identified as: building height, layout and spacing, building material and albedo, shading, ventilation and air-conditioning (Akbari et al., 2001; McEvoy et al., 2006). See section 5.3.4 below.

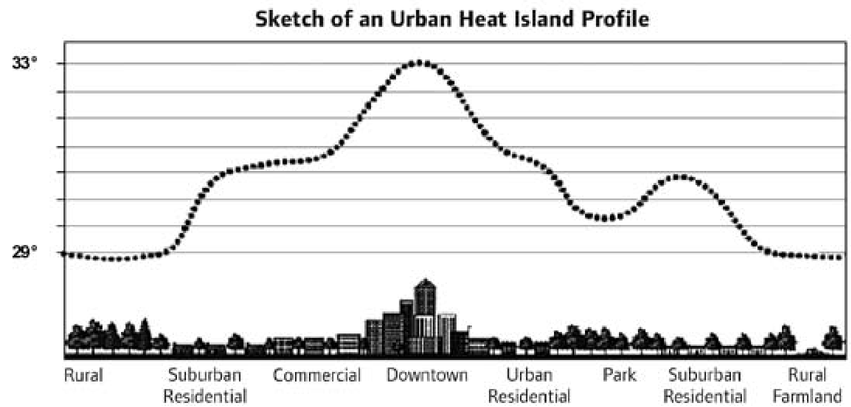

Figure 5.1 Building density and the urban heat island
Source: Mayor of London (2008)

5.3.2 Switch from fossil fuels to renewables

Any move away from fossil fuels to generate power for urban areas is likely to involve generation using renewable energy sources (biomass, wind, tidal, etc.) whilst renewable local micro-generation strategies include PV, solar, micro-hydro, wind turbines, and solar roofing tiles. The feasibility of carbon reduction via community-based energy policy within a local area, based on renewables and reduced energy demand, has been discussed by Kellett (2007). Paterson et al. (2008) discuss the risks for biodiversity potentially associated with a switch to hydropower generation in a highly valued environment.

The impacts of alternative renewables strategies are discussed in other chapters of this paper. Energy production within or adjacent to urban areas might have impacts upon biodiversity where this involves the use of urban brownfield to produce biomass or act as a windpower site, or where urban wildlife is disturbed, either permanently or temporarily before species can become accustomed (e.g. by wind turbines). Impacts of windfarms on biodiversity (birds) has been reviewed by Barrios and Rodriguez (2004) who conclude that bird vulnerability and mortality at wind power facilities reflect the combination of site-specific (wind-topography interaction), species-specific and seasonal factors at each location.

5.3.3 Carbon sequestration

Carbon is sequestered within the built environment in gardens, parks and brownfield sites. Pickett et al. (2008) quote work by Riemann et al. (2003) indicating that residential land contains more aboveground biomass than agricultural land. In addition, work by Pouyat et al. (2006) indicates there is higher soil carbon in residential lawns than in many forest soils.

The biodiversity effects of carbon sequestration as an adaptive measure in urban areas would depend on the nature of the new vegetation[6] and the preceding vegetation. Oberndorfer et al. (2007) have indicated that green roofs (see below) may have capacity to act as carbon sinks. Innovative technologies may offer some potential for carbon capture from vehicle exhausts close to source on highways by using porous concrete barriers (see: www.jsonline.com/story/index.aspx?id=547381) with benefits for air quality.

5.3.4 Building materials/technology

Innovative materials and technology are being introduced to save energy. The literature examining these measures does not, generally, discuss benefits for biodiversity, but these must be expected to result from the contribution to a reduction in emissions. Structural timber (and other wood) within buildings is a carbon stock - one timber built house may lock up 40 tonnes of CO_2 during its lifetime (AMICA, 2007). If timber buildings became more common and forests were planted to provide for this demand, then additional habitat opportunities could be created - depending on previous use of the land and the diversity and management of the productive forest.

Lovell (2007) has discussed the potential role of low-energy materials and innovative technology for housing as a strategy to contribute to climate change response. A proposed strategy is greater construction mass and insulation (to assist in reducing energy use in both hot and cool periods). Hacker et al. (2008) point to the value of higher thermal mass in reducing embodied and operational CO_2 emissions from housing. Looking at the commercial sector, Jenkins et al., (2008) emphasize the role that technologies such as computer efficiency, low-energy display technology and LED lighting can play in reducing office energy use and consequently heating load, which may otherwise need to be removed by energy-intensive air-conditioning. These authors also note the relevance of office location in total energy use. Holmes and Hacker (2007) and Urge-Vorsatz et al. (2007) discuss aspects of low-energy housing design. Gustavsson et al., (2006) have investigated the value of replacing concrete by timber - using timber results in a net reduction in CO_2 emissions.

Other mitigation measures in the built environment include “white-topping” asphalt, rainwater harvesting and re-use of wastewater. White-topping (increasing albedo) is a measure proposed to reduce temperatures within heat islands - which should result in cooler environments and lower cooling-energy use[7]. The mitigation potential of rainwater harvesting is partly direct - making

[6] Akbari *et al.* (2007) refer to work by Rosenfeld et al. (1992) which estimated that the direct sequestration of carbon dioxide is less than one-fourth of the emission reduction resulting from savings in cooling-energy use.

[7] See www.climatetechnology.gov/library/2003/tech-options/tech-options-1-2-4.pdf

water available within an immediate environment, and partly indirect, by (slightly) reducing energy used in pumping water. Re-use of wastewater has a similar value.

Hertin et al. (2003) have discussed the difficulties associated with changing building technologies, quoting Sorrell et al. (2000), who note the 'principal agent' problem [i.e. acting as a pioneer] as a "well-known barrier" to the introduction of energy efficiency measures in housing.

5.3.5 Green roofs and walls

The installation of green roofs and walls has been investigated for benefits for both mitigation and adaptation. Oberndorfer et al. (2007) discuss how green roofs (i.e. those covered with a rooting substrate and planted with sedum or other appropriate plants) can change roof albedo to reduce the urban heat island effect, as well as reducing energy demand by maintaining interior climates. Oberndorfer et al. (2007) also quote Bass et al. (2003), who found temperature reduction of 2°C achieved in some areas of Toronto, using a simulated 50% green-roof coverage. For each single building, a green roof reduces solar gain and so may reduce cooling energy use. It can also help with storm water management, directly provide urban habitats and may offer potential as a carbon sink (Oberndorfer et al., 2007). These authors quote other studies which document invertebrate and bird communities established on green roofs. Finally, design strategies to maximise biodiversity have been explored by Brenneisen (2006).

Green walls offer some of the advantages of green roofs in terms of cooling buildings, changing albedo, slowing the speed of drainage from building surfaces and offering biodiversity habitat. Bass and Baskaran (2003), working in Toronto, found that vertical gardens reduced summer cooling load "even more dramatically than the green roof" and suggest that urban heat islands could be significantly reduced by these technologies.

5.4 Adaptation Strategies and Measures

5.4.1 Design

A more spacious urban area, with more green spaces (and opportunities for habitats and biodiversity) is also likely to be cooler, promoting comfort and reducing the need for air conditioning (LCCP, 2002; London Assembly, 2005).

An increase in "bluespace" (open bodies of water: lakes, rivers, canals, etc.) is recommended by Shaw et al. (2007) and McEvoy (2006) to help cool urban areas, but also to provide opportunities for wildlife (London Assembly, 2005). There are references in the literature to tall, narrow streets as a route to protection from excessive sunshine (e.g., Marseilles - Shaw et al., 2007). The design has disadvantages at times of year with lower sun angles; whether this might have advantages for biodiversity has not been researched. Katzschner (2007) has analysed micro-climatic thermal comfort in cities looking at urban planning and open space design. Girling and Kellett (2005) propose approaches to achieve both compactness and ecological soundness in North American urban design.

UK research (Land Use Consultants et al., 2006) into new development in a coastal area (north Kent) has highlighted scope for designing increased flood capacity through watercourses, river channel restoration, and sequential use of land as recreational open-space then marshes as sea level rises. These measures will all provide spaces for biodiversity to inhabit. Kabat and Vellinga (2005) have discussed the need for “climate-proofing as an element of spatial planning and focus on the integration of water space into spatial plans”. Whilst they do not specifically refer to biodiversity, this space would offer habitats for species.

Compensation systems exist (e.g. in the Netherlands and Germany) which are intended to “re-balance” development and nature conservation. A compulsory compensation system for development impacts upon biodiversity has been in place in Germany for over 20 years. Legislation backing this includes the Federal Planning Act of 2004 (updated 2007), implemented under the local Bebauungsplan (Binding Land-use Plan), and at site-specific plan level, which includes a master plan (usually at a scale of 1:1000 or 1:500). The legislation requires that all development proposals be accompanied by an undertaking to provide compensation (or “counterbalances”[8]). Compensation areas are identified by the local authority and might typically be areas of agricultural or “waste” land with low ecological value, usually within the local authority’s possession; the upgrade of ecological value provides the required compensation. Where a brownfield site has acquired significant ecological value, compensation would also be required for development of that land. Where it is not possible to find sufficient compensation land within the local area, some on-site compensation may be used, such as green roofs. Whilst green roofs also offer mitigation for climate change, impacts of climate change are not directly addressed by this legislation. There is some variation in the application of the compensation arrangements between the various Bundeslander (Ganser, pers. comm., 2008).

5.4.2 Building design (“solar control”)

McEvoy (2006) notes that mitigation measures (such as building height, layout and spacing, building material and albedo, shading, ventilation and air-

[8] See http://www.iuscomp.org/gla/statutes/BauGB.htm, Section 1a: Consideration of environmental concerns

conditioning) are also important considerations for the adaptation agenda, and synergies should be exploited wherever possible (McEvoy et al., 2006). Holmes and Hacker (2007) discuss principles associated with “climate sensitive” building design, covering solar gain reduction, spreading of solar gain to reduce the thermal peak, providing low-energy ventilation and limiting use of cooling-energy. Reduction of solar gain (shading) may be provided by trees, window material and design, overhanging roofs, abats-soleil, green roofs and walls and roof insulation.

Amongst these strategies the following are most likely to provide increased opportunities for wildlife and biodiversity, and hence the ability of biodiversity to adapt to the changed climate:

- more green spaces at the neighbourhood scale, interlinked and semi-natural, with a mixture of species and heights of vegetation (ground, shrub-layer, trees). Sailor (1998) and Jeanerette and Larsen (2006) have investigated the urban cooling achieved with increased vegetation;
- avoidance of soil sealing and introduction of sustainable drainage measures to improve infiltration and thereby enhance groundwater and growing conditions for urban plants; including, permeable paving;
- more common tree planting in urban areas (Shaw et al., 2007);
- green walls and roofs, providing habitats (food and shelter) for birds, invertebrates, etc. (Brenneisen, 2006; Grant, 2006; McEvoy et al., 2006; Shaw et al., 2007);
- overhanging roofs, for shade, offering potential habitats for birds, bats, etc;
- provisions for development to compensate for impacts, to enhance biodiversity or to take measures to mitigate any loss of biodiversity; and,
- to provide for ecological networks as a landscape planning measure, in the wider landscape in which urban areas are set, to facilitate movement and spread of species (BRANCH Project, 2007).

Strategies presenting threats to biodiversity include the increased use of air-conditioning, which increases energy use and consequently emissions, without providing any opportunities for biodiversity. The installation of passive ventilation, with low or zero energy demand is only applicable to new buildings. Also, roof insulation may reduce roof space available to wildlife (e.g. bats).

5.4.3 Gardens, parks and greenspace management

Planned (and unplanned) changes within private gardens, public gardens and parks, and semi-natural areas within urban areas may all have significant impacts upon biodiversity habitat. Bisgrove and Hadley (2002) present research into impacts of climate change on gardens and parks. Adaptive changes may include:

- Changes to planted species in gardens and open areas, including “xeriscaping” - landscape design for dry conditions, which do not require supplemental watering (see Binning, 2007).
- Changes in lawn management: watering/irrigation; lawn replacement in heavily used areas; changes in frequency of grass mowing and other management.
- Expanding parkland and semi-natural areas, restoring wetlands.

Amongst these changes those which are most likely to favour biodiversity are greenspace expansion and the linking up of green areas into a network, including wetlands. Solecki and Rosenweig (2004) evaluate the efficacy of biosphere reserve strategies (with core, buffer and transition zones) in a large conurbation (New York City) using a carbon footprinting methodology[9]. McEvoy et al. (2006) have suggested regional parks near urban areas, which also would reduce distances travelled to escape the urban heat island as well as be capable of ‘hiding’ substantial recreational activity while reducing visitor demand on more vulnerable landscapes - with probable biodiversity benefits. Xeriscaping, on the other hand, which uses 'non-thirsty' native plants and drought tolerant exotics, will not necessarily offer food and shelter to existing wildlife species, though it may have some potential for biodiversity support within urban areas.

Within urban green areas there are unplanned changes as the result of plant and animal invasions, as well as planned plantings for resilience to anticipated climates. Both will have consequences for the species dependent on the species which were previously present, for food and shelter. So, where possible, appropriate species selection should consider this. Wilby and Perry (2006) point to the advantages for wildlife of less-frequent grass mowing in parks and gardens, whilst other measures may become necessary, such as water management (National Trust, 2005).

Bradley and Altizer (2007) have investigated risks from disease pathogens for humans and vulnerable wildlife populations and find varying and interacting responses with climate change. Adaptation measures to control newly introduced diseases within built-up areas, (e.g. spraying for biting insects/mosquitoes within urban parks) will affect a broader spectrum of biodiversity.

5.4.4 Increasing resilience to extreme weather in urban areas

Adaptation measures may be necessary in some locations to deal with unstable soils and slopes at risk of landslip in extreme rainfall events. Where the

[9] In the UK, Brighton & Hove are committed to becoming “the first UK urban biosphere reserve” (Brighton & Hove Council, 2006, p 41)

adaptation measures are designed to include deep-rooted vegetation and soakaways whilst likely erosion paths are closed or re-graded and restored to prevent gullying, there will be new opportunities for biodiversity habitats (Hau and So, 2002).

A range of climate-related factors can compromise the integrity of buildings (and other infrastructure). The most serious of these are flooding, wind and driving rain, subsidence and soil movement. Heat extremes are a further hazard to be faced. To adapt to these potential hazards the location and layout of development, landscape architecture, building design, appropriate use of materials and provision of outdoor spaces must be reviewed. Given the complexity of the climate change issue, holistic responses acting at a variety of spatial scales have been recommended (McEvoy, 2006).

Soil sealing (with hard surfaces) may be an adaptation both to weather (which makes open surfaces hard to manage), as well as to demographic and economic changes; however due to less infiltration, sealing increases flood risk as well as affecting biodiversity (London Assembly, 2005; Pauleit et al., 2005; RHS, 2005). Sustainable drainage systems (SuDS), which may be introduced as a response to flood risk under climate change, offer significant opportunity for biodiversity protection and improvement at the local level as well as can form part of a "green grid" across cities (ODPM, 2006).

Voogd (2006) describes the use of both technical and spatial measures as a distinguishing characteristic of the Dutch approach to solving water-related problems - stemming from the Netherlands "Room for Rivers" Spatial Planning Decision of 2006. Under this policy spatial planning measures are designed, for example, to change land use in order to (1) prevent fast run-off from surfaced areas, (2) enable and safeguard the storage and discharge capacity of the water system, and (3) prevent damage to built-up areas downstream. Obligatory measures in land-use planning are a water opportunity map (WOM) used to outline the relationship between water and land use, and the water assessment test (WAT) which presents the consequences of a proposed plan for water systems and water management. Technical measures such as increasing the capacity of rivers by deepening riverbeds and moving dikes and/or raising them are technical measures used. Retention areas for temporary relief in times of emergency have also been promoted in the Netherlands, but this has met with opposition (Voogd, 2006). Voogd notes that earlier analysis by the Netherlands Bureau for Economic Policy Analysis (CPB, 2000) had suggested that spatial measures may be more cost effective in the long term than technical measures. Water storage areas are part of integrated water and spatial planning in the Netherlands, discussed by Woltjer and Al (2007), who also outline the role of the Water Framework Directive as a factor in spatial planning. It could be expected that biodiversity would benefit from these innovations.

Improving resilience to extreme events, especially storm water flooding, is also a motive for designation of a New York biosphere reserve which could provide a floodwater catchment area (Solecki and Rosenzweig, 2004). Where washlands and flood defences are developed to cope with river flooding, perhaps as exacerbated by "urban creep" and soil sealing, these measures can provide opportunities for biodiversity. Morris and Hess (2005) suggest that there is potential synergy between flooding and biodiversity under some flood regimes; however biodiversity benefits mainly depend on the management of water regimes following flood events. They state: "There is a clear need to "join up" hitherto fragmented policy". Otherwise, evidence will continue to mount that urban planning is responding to some issues, e.g. flood risk, but not seeing benefits for biodiversity (Wilson, 2006).

Other adaptive measures associated with extreme events which may present threats to biodiversity include the re-siting of urban facilities (see 5.4.6 below) and the removal of street trees as a pre-emptive measure for storm wind damage.

An analysis of the urban and adjacent suburban area of Boston, USA analysed interdependencies of impacts of climate change adaptation strategies and infrastructure systems (Kirshen et al., 2008). The study used two climate change scenarios and three adaptation scenarios (Ride It Out, Green and Build Your Way Out - BYWO) and investigated the period to 2100. The infrastructure systems studied were: energy, flood defences (sea and river), transport, water, public health, tall buildings and bridges. Amongst the themes emerging from the analysis are:

- both the structural (BYWO) and less structural (Green) scenarios of response reduce the expected total negative effects upon infrastructure;
- under many scenarios, an effective adaptation soon will result in less total future negative impacts in a system, even if climate change does not occur;
- climate change will add significantly to the negative impacts of demographic changes upon infrastructure services in the Boston region;
- the climate change impacts of various infrastructure systems and their adaptation actions interact;
- adaptation of infrastructure to climate change must also consider integration with land use management, environmental and socio-economic impacts and the various institutions involved. A coordinated response strategy amongst institutions is seen as necessary (Kirshen et al., 2008).

5.4.5 Changes to urban management practices

Adaptation strategies for climate change which might be introduced for urban management under climate change include:

- changes to numbers and species of street trees (also discussed above),
- changes to street washing/cleaning;
- changes to waste management (more frequent collection, changes to landfilling practice);
- energy efficiency practices in public realm (street lights, etc.).

Amongst these changes, an increase in street trees would increase urban habitat potential; whilst climate change and a combination of measures such as modified waste management or increased watering of parks may affect the suitability of urban parks to support urban wildlife – although there may be negative indirect impacts from more water use. Parris and Hazell (2005) discuss impacts of park watering on bats in Melbourne.

5.4.6 Managed re-alignment and re-settlement (progressive inland movement of communities and infrastructure).

Approximately 140,000 km^2 of land in Europe currently lies within 1 metre of sea level, with increasing numbers of people threatened by sea level rise. An estimated 1.4 million people in Europe will be affected potentially by flooding each year under the A2 SRES scenario for the 2080s, in which 19,000 km^2 could be permanently lost (Richards and Nicholls, 2007). McGranahan et al. (2007) have estimated the share of urban settlements whose footprints intersect the Low Elevation Coastal Zone (i.e. land at an elevation within 10 m of sea level) by urban settlement size; this share ranges from 7% in Europe and Africa to 13% in Asia, Australia and New Zealand.

It seems likely that the gradual moving or inland "migration" of settlements as a result of managed realignment and retreat may become an adaptation strategy. Similarly, built infrastructure at risk of coastal or river flooding, such as coastal roads and rail links, emergency control stations, electricity sub-stations and water pumping stations, are likely to re-locate to more resilient sites (see also chapter 6 on river and coastal flood management). In all these cases there is the possibility that the new site selected may have significance for biodiversity or be a protected site; therefore, such a move could have adverse consequences for biodiversity.

Any large scale movement of people may put extra pressures upon water resources in specific regions, with indirect impacts upon biodiversity due to increased water shortage - particularly in arid areas such as the Mediterranean. Alcamo et al. (2007) indicate that the area under high water stress in Europe may be expected to rise from 19% today to 35% by the 2070s, affecting up to 44 million people.

In the same way, where both coastal and inland tourism sites re-locate in response to changing environmental conditions (see chapter 6 on rivers and the coastal zone) there is a risk of pressure upon biodiversity sites.

5.5 Conclusion

This section draws together conclusions for habitats and taxa, then summarizes conflicts and synergies arising from adaptation/mitigation measures and identifies those measures or strategies which may be considered to offer benefits for mitigation, adaptation and biodiversity (win-win-win). Measures which assist in avoiding negative impacts are also noted. Figure 5.2 below illustrates the MACIS team's assessment of the effects of mitigation and adaptation measures on biodiversity within the built environment sector. Figure 5.3 presents a risk matrix adaptation and mitigation impacts upon biodiversity within the built environment.

5.5.1 Habitats and taxa

The habitats found within urban and other built environments (e.g. those associated with major infrastructure) are of course different to those of other chapters in this report in that they have been created for specific purposes (gardens ands parks) or have arisen spontaneously in harsh conditions (e.g. on brownfield sites). Moreover, the extent to which these habitats are affected by climate change will depend upon the extent to which they continue to be managed: e.g. watering or increased pressure from other activities. Without any change or increase in management, it seems likely that any semi-natural areas of woodland or grassland within built areas are at greatest risk from climate change amongst built environments – especially as they are also at risk of development. We can perhaps expect that planting in parks and gardens will be gradually adapted to new climates by their managers – but this will add to the impacts upon the animal species that inhabit them. Table 5.2 below summarizes the MACIS team's assessment of climate change strategies habitats and species within the built environment

5.5.2 Conflicts

Adaptation to climate change in the built environment sector (urban areas, built infrastructure and construction) may induce conflicts between mitigation and adaptation objectives. Some adaptive measures will be taken by individuals as a result of behavioural changes. These might include: greater use of air conditioning, the sealing of open areas, or the removal of mature trees near houses if they are seen as a storm risk. All these will probably have negative impacts for biodiversity and so are examples of "maladaptation". More frequent watering of greenspace and gardens, helping to support "managed" biodiversity in dry conditions, may be considered maladaptive as it may increase energy use and actually reduce water available for biodiversity elsewhere. Some mitigation and adaptation measures entail potentially adverse impacts, e.g. disturbance or fragmentation of habitats associated with changes in transport networks and travel behaviour. The design of new or regenerated urban areas cannot be resolved without reference to specific cases and requires further research: for example, whether it should be relatively dense – reducing transport emissions but also reducing available green space – or relatively scattered and therefore cooler, but inevitably encroaching further onto rural land.

Table 5.2: Summary of impacts of mitigation and adaptation measures in the built environment

	Biodiversity Impact†		Habitats affected					Taxa affected					
Strategy	Impact under inappropriate use	Impact under best management practice	Parks and gardens	Semi-natural scrub/woodland	Semi-natural grassland	Other green spaces* inc. avenues, fields*	Urban wetlands, watercourses	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants
Urban design	↘	↗	•					•	•			•	
Building design (“solar control”)	↘	S							•				
Gardens/parks and greenspace management	↓	↗	•			•	•	•	•			•	•
Increasing resilience to extreme weather	↓	↗	•	•	•	•	•		•	•		•	•
Changes to urban management practices	↘	S						•	•				•
Re-settlement	↓	S		•	•	•		•	•	•		•	•

† ↑ Highly beneficial for biodiversity, ↗ Moderately beneficial for biodiversity, ⇔No known effect on biodiversity, **S** Stabilisation (prevents further deterioration); ↘ Moderately detrimental for biodiversity, ↓ Highly detrimental for biodiversity.
***** Other green: landscaped areas, street trees/avenues, playing fields, etc. □ - net effect on biodiversity/not quantifiable at present

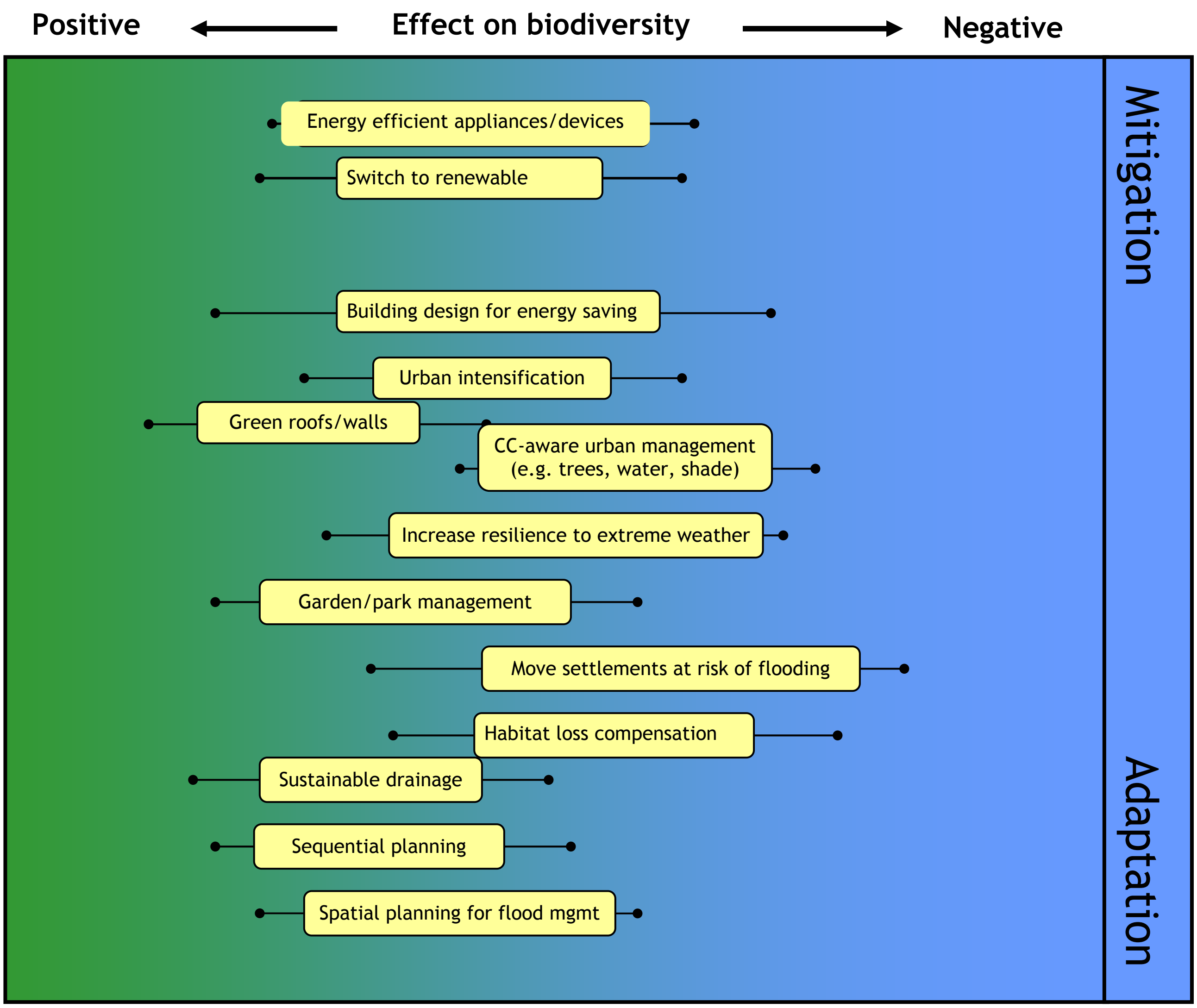

Figure 5.2 Effects of mitigation and adaptation measures on biodiversity, built environment sector

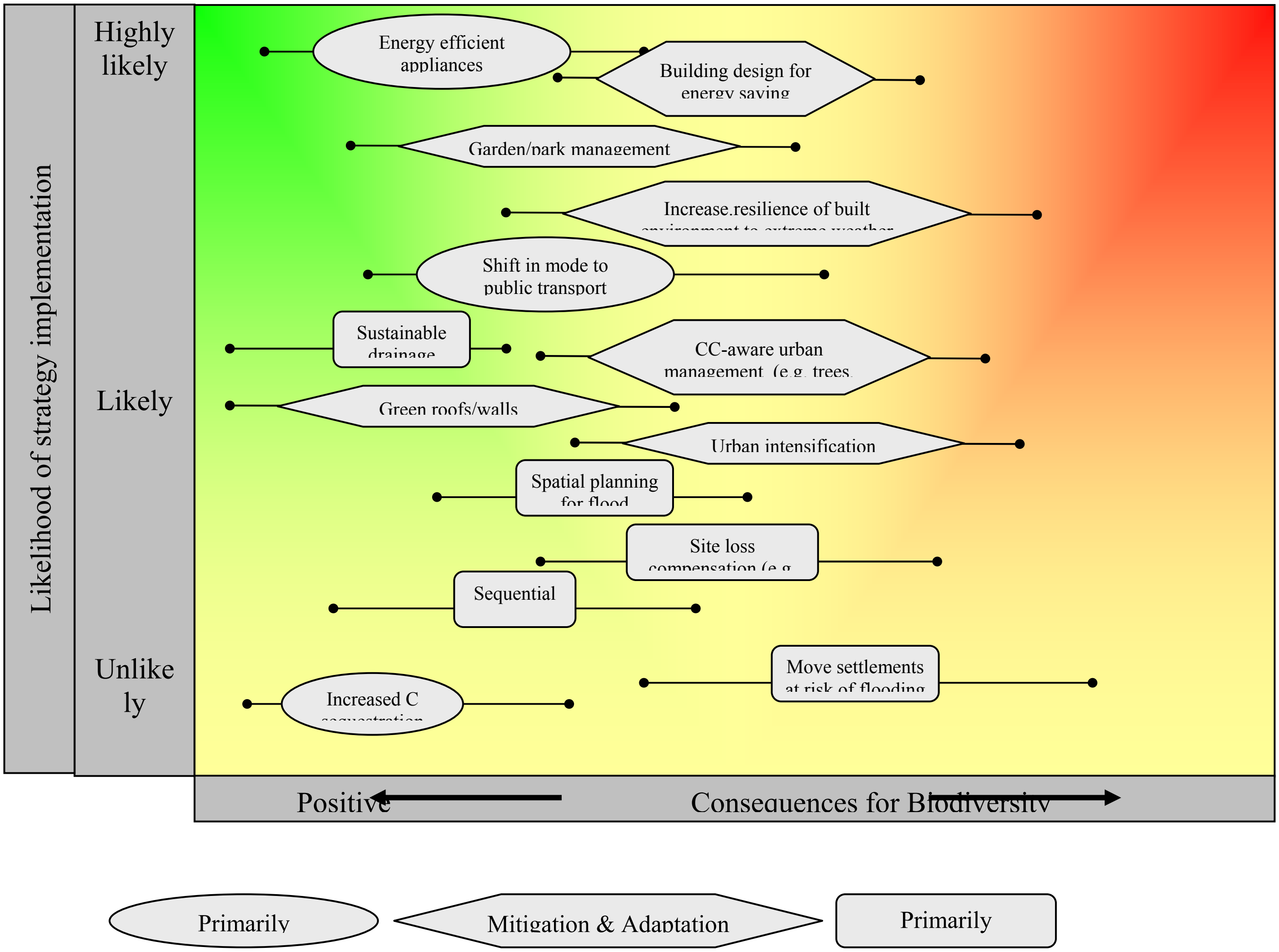

Figure 5.3: Risk matrix for built environment of adaptation and mitigation impacts upon biodiversity

5.5.3 Avoiding negative impacts

In the built environment, important measures to assist in avoiding negative impacts upon biodiversity may apply under two sets of circumstances: (1) where new developments are planned and undertaken, and (2) where plans are devised for existing built areas (re-modelling or regeneration). In these cases the various forms of environmental assessment must generally be used: EIA for projects, SEA for plans and Habitats Regulations Assessments where any "European sites" within the Natura 2000 network might be affected. Such assessments are carried out to identify baseline conditions and potential impacts, including cumulative impacts, then determine the significance of such impacts and, where necessary, provide measures for impact mitigation. For example, with regards to wetland habitats within urban areas, special protection will need to be provided in order to maintain flows of water into the wetland. For the most part, assessment of the likely impacts of climate change has not been formally required in the past, though some impact assessment work has included it (Piper et al., 2006).

In broader terms, however, negative impacts are best avoided by ensuring that environmental conditions are maintained or ameliorated (in terms of flows of water and nutrients, opportunities for water infiltration and extent of exposure or shelter). In locations where increased storminess leads to a reduction in large mature trees, provision of a larger number of trees of more wind-resistant stock maybe helpful. Increased protection from disturbance by people may also contribute to avoiding cumulative adverse impacts on birds and other animals at specific times (e.g. breeding periods).

5.5.4 Synergies

Some policies and measures may act positively and synergise for biodiversity, where interactions between measures provide suitable spaces with adequate linkages and networks as well as sufficient water resources, which can be successfully occupied by wildlife. Such measures also can lead to further benefits for people with improved functioning of urban areas.

At the level of individual buildings, adaptation measures with benefits for biodiversity include green roofs, over-hanging roofs and tree planting for shade. Adaptation measures and policies at a wider scale may offer benefits, particularly those associated with water infiltration and retention or associated with an increase in green and blue infrastructure, with the protection of any semi-natural areas. These also offer opportunities for more sustainable recreation, e.g. walking and cycling.

5.5.5 Win-win-win

This literature review has indicated there is an array of options for climate change mitigation where opportunities for adaptation should be taken into account (at the development design or regeneration stage) in the built environment sector. In these cases the value of the measures for biodiversity is often indirect, i.e. acting to reduce pressures which increase emissions and climate change. In addition to emissions reduction, some of the measures discussed also offer direct benefits for biodiversity. For example green roofs may offer: energy savings, carbon sequestration, storm water management and additional habitats. Direct benefits may accrue from some forms of biomass production, where disturbance of species and habitats is reduced and where heat levels in the urban heat island are lowered. Likewise, developing habitats in association with walking and cycle-paths – which help with mitigation and adaptation - could also have direct benefits for biodiversity.

There are many adaptation measures available which can ease human adaptation to climate change and at the same time either directly or indirectly improve conditions for biodiversity in urban areas, offering potential for more resilient habitat. These measures include sustainable drainage systems and new flood retention capacity, additional erosion-proof habitats and flood provision, as well as green spaces, trees planted for shade, water bodies for cooling.

See MACIS WP 4, deliverable 4.1, on policy issues, for an examination of conflicts and synergies for biodiversity resulting from mitigation and adaptation measures in different policy sectors.

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6. River and coastal flood management

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6.1 River flood management

Floods are a natural part of the functioning of rivers, but due to human modifications of the catchment (e.g. drainage, urbanisation) and through channel modifications (e.g. straightening, embankments) the volume of flow and speed of runoff have increased, while actions such as abstraction have decreased flows. In addition, the quality of water has altered through pollution. Climate models project that higher precipitation extremes in warmer climates are very likely to occur and that precipitation intensity increases almost everywhere, particularly at mid- and high latitudes where mean precipitation also increases; thereby increasing flood risk (Kundzewicz et al., 2007). There is still uncertainty, as shown for the UK, where depending on which GCM is used, the importance of snowmelt contribution and catchment characteristics and location, the impact of climate change on the flood regime (magnitude and frequency) can be both positive or negative (Reynard et al., 2007).

In many regions, therefore, adaptation strategies will be necessary for flood risk management, and the need for an ecosystem approach to water management is increasingly being recognised (Mata and Budhooram, 2007). This may take the form of sustainable flood management and in urban areas it is part of Sustainable Urban Drainage Systems (SUDS – see chapter 5). There are a number of European examples of sustainable flood management using a combination of the methods described below in Baker and van Eijk (2006). Adaptation to floods through river management will change many aspects of the hydrology and ecology of both the river and the surrounding catchment. Floods also are essential for the ecological functioning of riverine and adjacent wetland communities. They not only control the population dynamics of the various wetland species and the dynamics of ecological interactions, but also their diversity. There is little information on the impacts of the flood control measures themselves but there is a considerable literature on river and wetland restoration, where the focus is on restoring a more naturally functioning rivers and ecosystems. Inferences can then be made about some of the flood adaptation and mitigation measures. River rehabilitation schemes are now widespread in the UK and elsewhere, but even here their effects on river biota are poorly understood (Swales, 1988) and there have been few systematic assessments of their ecological effect, particularly on target organisms such as fish (Pretty et al., 2003).

6.1.1 Ecological effects of flooding

Submergence can cause a reduction in plant biomass, probably through oxygen stress (He et al., 1999), while re-exposure to oxygen after a period of oxygen deprivation may lead to post anoxic injury in such species (van Eck et al., 2004). On inundation, soil organisms can also experience swelling, respiration problems when the entire body is surrounded by water and the oxygen content in the water is low, being moved out of the habitat by flowing water, and being affected by toxic substances that are formed in flooded soils or by contaminants from the river water (Plum, 2005). With the depletion of oxygen, the concentration of CO_2 rises, and NH_4, which is toxic to soil animals, accumulates.

The effect of flooding is also realised through light availability, which can be related to depth of flooding and amount of suspended sediment. It is not certain exactly how light, depth and other factors affect wetland plants, but experiments have shown that the extent to which a species survives a period of flooding is dependent on light intensity (He et al., 1999). Depth may have an influence through light or independently through hydrostatic pressure.

Species distribution in floodplain grasslands have been shown to be correlated with flood survival, with relatively flood tolerant species occurring mainly at low elevations along the floodplain while more flood sensitive species were restricted to high parts of the floodplain gradient (van Eck et al., 2004). Also extreme floods in summer may move the lower boundary of a species' distribution upwards or may lead to the elimination of a species from the floodplain (Vervuren et al., 2003). Experimental research suggest that the zonation patterns, as created by occasional summer floods, may be maintained for a long time, probably due to the limited ability of species to re-colonise lower positions in the floodplain (van Eck et al., 2004).

The significance for biodiversity depends on the existing habitat, community and species composition (which may be constrained by many factors, including historic pollution) and the magnitude of habitat change. In dynamic systems, it is likely that the ecosystem will be relatively robust, adapting to change within a relatively short timescale; however, if flood frequency and magnitude changes significantly it is likely that the geomorphology of the system and hence the habitats that are represented will change (Evans et al., 2004a). Species may be sensitive to alterations for flood management in such interrelated factors as the frequency, magnitude, timing, duration, depth of flooding, as well as changing channel flow patterns and geomorphology. The three main aspects to consider in resolving potential conflicts in drainage management relative to different biodiversity objectives in washlands[10] are the

[10] The study defines a washland as “an area of the floodplain that is allowed to flood or is

pattern and frequency of inundation, the depth of inundation, and the retention of appropriate water levels after flooding (Morris et al., 2004).

The frequency of flooding will affect the plant community, but the magnitude is also important as it affects the degree of submergence. If complete submergence occurs, then underwater light availability becomes an additional factor, determined by the amount of water and submergence depth. If flooding is relatively shallow and some vegetation remains exposed, then invertebrate survival is enhanced and damage to nesting birds in the case of summer flooding is reduced (Morris et al., 2004). Vervuren et al. (2003) found that light and depth have similar effects on the riverine plant tested and that suspended load moved the lower boundaries of species, with the effects most pronounced in light sensitive species. They concluded that underwater light availability, but not pressure related effects of water depth, may differentially affect species' survival.

The timing and duration of the flood have been seen as the main factors influencing species' survival (Toner and Keddy, 1997), although duration may not affect the recovery of most flood tolerant species (van Eck et al., 2004). Morris et al. (2004) used flooding seasonality and duration as two of their variables for classifying washlands. A study of terrestrial grassland species showed that all species survived longer under winter floods than under summer floods (van Eck et al., 2006); however, responses upon flooding were species-specific. All summer flood tolerant species had high tolerance for winter floods as well, but summer flood sensitive species survived either a little or dramatically longer when flooded under simulated winter conditions. Flooding adversely affects the density of soil macroarthropods. A study showed that the magnitude of this effect could be related to the duration of flooding and the high temperatures that prevailed during the previous summer and early autumn, with post flood survival most likely dependent on horizontal migration and/or recolonisation by specimens from more elevated sites (Frouz et al., 2004). Birds are unable to feed and prepare for breeding if flooding is prolonged into the spring and waders are generally intolerant of summer flooding which disrupts breeding (Morris et al., 2004). The timing of flooding, the underlying soil type and the flooding history are all important in determining the impact on the soil invertebrate community (Ausden et al., 2001). Some invertebrates are affected similarly to soil macroarthropods, but are also intolerant of flooding beginning earlier than December. Prolonged flooding will kill and expel species, which reduces biodiversity including invertebrate diversity, such as butterflies, which can be reliant on flood sensitive species. This can have consequences up the food chain, as winter flooding of previously unflooded areas greatly reduces the soil macroinvertebrate prey of many breeding birds, largely as a consequence of

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deliberately flooded by a river or stream for flood management purposes, with potential to form a wetland habitat". This definition includes areas which provide natural storage as well as artificial storage (Morris et al., 2004).

invertebrates vacating flooded areas (Evans et al., 2004a).

The management of the water levels post-flooding is critical for both biota dependent on grassland, woodland or aquatic habitats, (e.g. oxbows, ponds and drainage channels) and for meeting the various needs of wading birds as well, although overall they are reliant on a shallow water table (Morris et al., 2004). The quality of water to be stored is an issue (van Kampen-Brouwer et al., 2004) as urban runoff can have a particularly negative impact on biodiversity, although biodiversity also can be important in improving its quality (see Section 6.6).

River flood management can affect the survival, abundance and distribution of species, but there are many opportunities to develop win-win situations for flood management and biodiversity. An assessment in the Meuse river basin of the ecological effects of three flood protection measures: retaining water to slow down runoff, retention of peak discharges and increasing discharge capacity, using a scenario approach has shown that there is a good chance to combine floodplain environmental rehabilitation aims with flood protection activities, both on a local and on an international scale (Geilen et al., 2004). Other studies also have shown the possibility of combining flood management and ecological objectives in the context of the Rhine and Meuse river basins (Baptist et al., 2004; De Nooij et al., 2004) as well as a number of case studies included in Morris et al. (2004).

6.1.2 River flood management and mitigation

The scale of some of the flood risk management strategies means that their impact on climate change mitigation is minimal (e.g. detention ponds), although cumulatively there may be grounds for inclusion in any carbon accounting schemes. Larger scale measures, such as wetland restoration, may contribute to climate change mitigation, as wetlands account for approximately 37% of the terrestrial carbon pool (Bolin and Sukumar, 2000), and therefore have a high potential to help mitigate climate change (Pant et al., 2003; Euliss Jr et al., 2006).

The flood risk management strategies can be negative or positive for mitigation depending on the form of the management, for example:

i. Storage of water by flooding land can lead to carbon sequestration in debris and other organic material in sediments. This can, however, result in release of methane (a more effective greenhouse gas than carbon dioxide) from anaerobic decomposition. Most studies are on large dams, and it has been shown that the Tucuruí dam had 60% as much impact on global warming as a coal-fired plant generating the same amount of electricity, while the Balbina dam had 26 times more impact (Fearnside, 1995; Pearce, 1996).
ii. Conservation of wetlands can lead to avoided carbon loss if wetlands

were to be drained and replace by low biomass ecosystems
iii. Re-creation of wetlands can lead to carbon sequestration.

6.1.3 River flood management and adaptation

The greatest amount of construction work, as a means of adaptation to climate change impacts will be in water management and in coastal zones (Klein et al., 2007). This will involve a variety of hard protection measures, which affect the river itself in term of magnitude, timing of flows etc. and impact mostly indirectly on biodiversity. Softer measures, however, such as managed realignment and ecosystem restoration, will rely more on harnessing natural processes and impact more directly on biodiversity.

There are a suite of possible flood management adaptation strategies and in the UK Foresight project (Thorne et al., 2007), the literature review and expert and stakeholder consultation led to the identification of 80 possible response measures, policies and interventions for reducing the catchment and coastal-scale risks of flooding[11]. These were merged into 26 functional response groups consistent with the source-pathway-receptor model and five themes. They form the basis for the mitigation and adaptation flood responses considered here and their impacts on biodiversity, although the coastal ones form a separate section. For many, there was no information on their biodiversity impacts and thus there is a need for further research on some measures in order to fill in these information gaps, while others, such as flood insurance are unlikely to have any impact. Many of the identified measures are not implemented in isolation and also they can form part of adaptation and mitigation in other sectors, in particular agriculture and urban areas (Chapter 10).

6.1.4 Managing the rural landscape

The aim is to manage catchments to increase infiltration and groundwater replenishment, retain excess surface runoff through enhanced storage in times of flood and manage surface runoff through altering the hydrological properties of the surfaces.

6.1.4.1 Rural infiltration: water retention and management of infiltration into the catchment

6.1.4.1.1 Changing tillage practice (see Chapter 2 for reduced or no-tillage)

Mitigation measure: Increased water retention capacity of soils could enhance CO_2 sequestration, but if soils become water logged then methane emissions

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11 http://www.foresight.gov.uk/Previous_Projects/Flood_and_Coastal_Defence/Reports_and_Publications/Volume2/Chapter2.pdf

could increase.
Adaptation measure: Increased infiltration and/or storage, reduced rate of runoff through reduced or no tillage, use of cover crops.
Impact on biodiversity: Positive and negative

6.1.4.1.2 Extensification (see Chapter 2)

Mitigation measure: Possible carbon sequestration.
Adaptation measure: Use of land less intensively, maintaining cover.
Impact on biodiversity: Generally positive.

6.1.4.1.3 Field drainage (see Chapter 2)

Mitigation measure: Increased water retention capacity of soils could enhance CO_2 sequestration, but if soils become waterlogged then methane emissions could increase.
Adaptation measure: Removal or reduction in the efficiency of ditches and drains to increase storage. Footdrains (shallow channels historically used for drainage) can be used to create localised flooding through maintaining high water levels in surrounding ditches (Eglington et al., 2008).
Impact on biodiversity: Beneficial for wetland species, negative for species sensitive to flooding. Fields with high footdrain flood densities attracted significantly higher densities of nesting lapwing (Vanellus vanellus) and are thought to be positive for other waders (Eglington et al., 2008). Grassland waders benefit from the maintenance of high water tables until mid-summer and the provision of pools where wader broods may feed on aquatic prey (Ausden et al., 2003).

6.1.4.1.4 Afforestation (see Chapter 3)

Mitigation measure: Carbon sequestration.
Adaptation measure: Reduction in total and rate of runoff through increased evapotranspiration, interception losses and throughflow and decrease in overland flow. The effects will vary with afforestation type.
Impact on biodiversity: Positive and negative. It depends on the original vegetation and the species planted, but generally involves the replacement of grassland or shrubs by trees (Farley et al., 2005). This can lead to nutrient depletion and increased soil acidity (Jackson et al., 2005), but if native species tolerant of projected climate changes are used then it could be positive for biodiversity, especially if habitat connectivity is increased (Chapter 9).

6.1.4.1.5 Buffer strips and buffering zones

Mitigation measure: Possible small-scale mitigation through increased carbon sequestration.
Adaptation measure: Reduced runoff; local scale, little evidence of effectiveness at the catchment-scale.
Impact on biodiversity: Beneficial. Introduction of grassland buffer strips reduces the risk of nutrient leaching and runoff into watercourses (Heathwaite et al., 1998; Haygarth, 2005; Withers and Haygarth, 2007).

6.1.4.2 Catchment-Wide Storage: water retention through storage at all scales

6.1.4.2.1 Detention ponds and bunds

Mitigation measure: May increase local carbon storage, but could increase methane release.
Adaptation measure: Storage to reduce runoff.
Impact on biodiversity: Positive and negative. Similar to wetlands and washlands (6.1.4.2.2) but on a much smaller scale, possibly temporary or ponds may be kept dry). On farms, storage ponds may only have a small potential for increasing biodiversity (van Kampen-Brouwer et al., 2004). In the restoration of the R. Dilje, Belgium, however, the banks of ponds have been excavated to make room for reed fringes to encourage the return of bittern (Botaurus stellaris) and night heron (Nycticorax nycticorax) (in Morris et al., 2004). Detention ponds may also have a mixed effect through trapping heavy metals, which decrease water quality in the pond, but improves that of any runoff (Färm and Waara, 2005).

6.1.4.2.2 Wetlands and washlands

Mitigation measure: Carbon sequestration, but also could lead to release of methane through anaerobic decomposition.
Adaptation measure: Creation or management of wetlands and washlands to increase water storage, slow runoff.
Impact on biodiversity: Washland (re)creation has no major adverse implications and is beneficial (Watkinson et al., 2007a), through potential for (re)creation of important habitats of conservation concern and their associated species. Flood duration, flood seasonality and wetness conditions in the washland are the key factors that determine the potential type and quality of the habitat (Morris et al., 2004). The retention of surface and soil wetness beyond the flood event period is a particularly critical determinant of habitat quality. The habitat potential mainly depends on land and water management practices beyond the flooding period, especially the management of groundwater levels. The same is likely to be true for wetlands. Habitats that could be created range from hay and flood meadows, through carr to reedbeds and swamps (see Table S2 in Morris et al., 2004). Morris et al. (2005) have also devised a framework for integrating flood defence and biodiversity in washlands, which could help in the realisation of potential synergies between flooding and biodiversity under some flood regimes

Re-creation of wetlands and washlands can increase habitat and facilitate the return of sensitive species e.g. snipe (Gallinago gallinago) (Evans et al., 2004). Flooding of grassland could reverse the decline of grassland waders (Wilson et al., 2004), but if sheet flooding is prolonged, it often reduces the abundance of soil invertebrate prey, especially earthworms (Ausden et al., 2001). It also results in sward death, thereby reducing the value of the grassland for grazing or hay cropping (Mountford et al., 1997). Maintenance of high water tables until mid-summer is desirable to ensure that soils remain soft, and to provide pools where wader broods may feed on aquatic prey (Ausden et al., 2003). In principle, this could be achieved by raising water levels in adjacent ditches; however, the practicability of this approach depends upon the hydraulic conductivity of the soils, which are sufficiently high in peat but negligible in marine clays.

Indirectly wetlands and washlands can also increase certain biodiversity through trapping sediments and pollutants, thus improving water quality. Similar effects can be seen in urban environments (e.g. see Section 6.1.5).

6.1.4.2.3 Riparian and floodplain impoundments

Mitigation measure: Carbon sequestration, but also could lead to release of methane through anaerobic decomposition.
Adaptation measure: (temporary) storage of water.
Impact on biodiversity: Mostly negative as habitats/species are submerged, but this would depend on the duration of flooding. Minimal benefit to aquatic species, but in a warmer climate this could include disease carrying vectors, such as Anopheles mosquitoes for malaria. Depending on the frequency and timing of flooding it may be possible to enhance biodiversity (Lane et al., 2007), for example, the restoration of the riparian zone can increase species richness, enhance fisheries by providing shading and shoreline habitat and increase connectivity between habitat areas (van Kampen-Brouwer et al., 2004).

6.1.4.3 Rural Conveyance: altering the volume and timing of runoff

6.1.4.3.1 Management of hill slope connectivity

Mitigation measure: Not applicable.
Adaptation measure: Decrease connectivity to river to slow runoff.
Impact on biodiversity: Positive and negative. Positive, in that it will reduce the danger of species being swept into the river, and also enable a river to re-connect with its floodplain. Negative as many species rely on connectivity for dispersal e.g. to breeding grounds, but this is probably minimal on hillslopes.

6.1.4.3.2 Drainage channel maintenance

Mitigation measure: Minimal carbon sequestration through increased vegetation.
Adaptation measure: Reduce riparian management to decrease speed of overland flow to river network e.g. through blocking upland drains or allowing vegetation to grow. It can increase frequency of inundation.
Impact on biodiversity: Positive in increasing habitat for river and riparian species.

6.1.4.3.3 Drainage channel realignment

Mitigation measure: Not applicable.
Adaptation measure: Modification of channel geometry, such as re-meandering to decrease flow rates.

Impact on biodiversity: Positive for lotic (slow flowing) river species, which are missing from many European rivers (Buijse et al., 2002). One to two years after re-meandering, species richness of wetland macrophyte assemblage has been shown to recover to at least pre-restoration levels, but macroinvertebrate species richness recovery was more variable (Biggs et al., 1988); although the density of the macroinvertebrate community can increase (Friberg et al., 1998).

6.1.5 Managing the urban fabric

Aimed at reducing the downstream flood risk, through management of above ground surfaces and pathways, channels, flow routes and storage above and below ground. Many aspects are covered in the built environment chapter.

6.1.5.1 Urban Storage: increase storage in urban areas

6.1.5.1.1 Building design (see Chapter 5)

Mitigation measure: Reduced energy usage in case of green roofs.
Adaptation measure: Increase storage/reduction of runoff rates e.g. through green roofs, ponding on roofs, disconnection of downpipes or rainwater harvesting (Evans et al., 2004a). Studies in Berlin have shown that rooftop gardens can absorb 75% of incident precipitation, which can lead to an immediate discharge reduction to 25% of normal levels (Stifter, 1997). Retention rates in summer can vary between 70-100% and in winter between 40-50%, depending on the rooftop garden design and the weather conditions. A grass covered roof with a 200-400mm layer of substrate can hold between 100-150mm of water (Minke, 1982 in Bass and Baskaran, 2003). The quality of runoff from rooftop gardens can vary, but often they improve it by removing pollutants, such as heavy metals (Johnston and Newton, 1996). A study on an experimental green roof (wild flower meadow growing in 150mm of lightweight soil), with a bituminous roof as a control showed that in three rain events (10mm in 12 hours) runoff was delayed by 45 minutes and the runoff rate was reduced by 75% (Bass and Baskaran, 2003).
Impact on biodiversity: See Chapter 5, Section 5.3.5. Any improvement in water quality should be beneficial. In Europe, they have been used as a part of wildlife corridors in urban areas and to mimic endangered habitats (Peck et al., 1999). Peck et al. (1999) also have identified other biodiversity benefits of green roofs, including providing:

- increased (island) habitat availability;
- stepping stones for species which are aerially dispersed;
- homes to sensitive plants that are easily damaged by trampling and to ground-nesting birds and undisturbed soil, which can increase insect diversity.

Studies of low-impact design practices for stormwater (e.g. raintanks, swale, raingarden and catchpit inserts) in New Zealand show that they reduce sediment and pollutant loads, stormwater flows, impervious surface area and increase vegetated areas (habitat area). These lead to off-site benefits in waterways (improved fish habitat) and estuaries (improved habitat derived from reduced contaminant and sediment accumulation), and for terrestrial local biodiversity (native vegetation corridors) (Pandey et al., 2005).

6.1.5.1.2 Urban area development

Mitigation measure: Possible carbon sequestration or avoidance of emission in promotion/ conservation of green spaces respectively.
Adaptation measures: Management of location of development (see Chapter 5), drainage, form and nature of buildings, flood barriers (for individual buildings), abandonment of areas/properties most at risk, promotion of green spaces (see Chapter 5 section 5.4.3), sacrificial areas for local storage and improve/extend flood embankments (based on Evans et al., 2004a).
Impact on biodiversity: see Chapter 5, especially 5.4.1. and 5.4.3. Green space can be used to enhance the connectivity of urban areas.

6.1.5.1.3 Detention ponds

Mitigation measure: Possible carbon sequestration in debris/organic sediment with potential methane emissions from anaerobic decomposition.
Adaptation measure: Create scrapes, hollows and ponds to increase flood storage capacity and duration.
Impact on biodiversity: Positive and negative. The positive impacts result from the increase of wetland habitats and biodiversity, but only for species tolerant of flooding/wetness. The nature of the pond banks has been shown in Nijmegen, Netherlands to affect the vegetation and macrofauna, as can shoaling (Urban Water Project Partnership, 2008). Stormwater pond surface waters can have poor water quality indicators, accumulate large masses of algae, including some harmful algal species, be the sites of fish kills, accumulate debris and trash, exhibit high concentrations of nutrients, chlorophyll a, chemicals, pesticides, fecal coliform bacteria (FCB), and have low dissolved oxygen (DO) concentrations (South Carolina Dept. of Health and Environmental Control, 2007).

6.1.5.1.4 Stormwater source control

This involves the management of stormwater as close as possible to origin.
Mitigation measure: Not applicable.
Adaptation measure: Increased permeability of surfaces e.g. pervious pavements, storage e.g. ponds (see 6.1.5.1.3).
Impact on biodiversity: Positive and negative. The positive impacts result from the increase of wetland habitats and biodiversity, but only for species tolerant of flooding/wetness. A study of retention stormwater wetlands based on drainage type, including residential, commercial and highway sites, showed that commercial sites had the lowest nesting success and the lowest diversity of invertebrate foods (Sparling et al., 2007). Mean nest success values for the

three types of wetlands, especially for highway drainages, were comparable to published values from natural wetlands. Over two years of study, highway ponds collectively served as source populations, whereas residential and commercial sites were population sinks in one year and sources in the other. They concluded that these sites can be valuable habitats for nesting birds in urban and suburban areas.

6.1.5.1.5 Underground storage

6.1.5.1.6 Temporary flood storage (e.g. in parkland)

6.1.5.1.7 Storage along/adjacent to flood system

No information found. Effects of all three above are probably similar to other storage systems e.g. section 6.1.4.2.

6.1.5.1.8 Groundwater management

Management of groundwater to ensure infiltration during high precipitation events.
Mitigation measure: Not applicable.
Adaptation measure: Control of groundwater levels, prevention of groundwater entering sewage/drainage pipes, maintenance of permeable cover (Evans et al., 2004a).
Impact on biodiversity: The limited information available for groundwater schemes indicates that they are not detrimental to invertebrates, but their impact is dependent upon factors such as the extent and timing of flow augmentation (Boon, 1988). The extent of raising groundwater level could also be important.

6.1.5.1.9 Rainwater harvesting

Mitigation measure: Possible reduction in energy used for pumping water.
Adaptation measure: Collection and use of potential floodwater, thus reducing runoff.
Impact on biodiversity: Positive and negative. Tanks for storage can take up a large proportion of small gardens (Pandey et al., 2005). The water can provide a breeding ground for insects, which may be disease carrying e.g. mosquitoes (Basher, 2000).

6.1.5.2 Urban Infiltration: increase infiltration in urban areas

6.1.5.2.1 Permeable land cover

Mitigation measure: Not applicable.
Adaptation measure: Permeable pavements can reduce storm runoff and increase groundwater recharge (Scholz and Grabowieckia, 2007).
Impact on biodiversity: Indirectly positive, as permeable pavements can reduce hydrocarbon contamination by 98.7%, with bacteria and fungi enhancing biodegradation (Scholz and Grabowieckia, 2007).

6.1.5.2.2 Building design

See Chapter 5

6.1.5.3 Urban Conveyance: manage conveyance of flood waters through urban areas

6.1.5.3.1 Design of building drainage

6.1.5.3.2 Urban drainage infrastructure

No information found.

6.1.5.3.3 Urban area development

See Chapter 5

6.1.5.3.4 Source control and local sustainable water system management (Similar to 6.1.5.1.4)

6.1.5.3.5 Controlling pathways of runoff

6.1.5.3.6 Multiple drainage systems

6.1.5.3.7 Water reuse and recycling etc

6.1.5.3.8 Managing wrong connections

6.1.5.3.9 Separating foul- and storm-sewers

6.1.5.3.10 Off-site pumping

6.1.5.3.11 Aesthetic use of water in urban area

6.1.5.3.12 Active dynamic real-time operation

6.1.5.3.13 Pumping off site

6.1.5.3.14 Design of roads and gully pots

6.1.5.3.15 Alter river channels to improve outfalls

No information found.

6.1.5.3.16 Reopen culverted watercourses (daylighting)

Mitigation measure: Not applicable.
Adaptation measure: Can reduce runoff velocities and increase hydraulic capacity.
Impact on biodiversity: Positive. It can create aquatic and riparian habitat, improve fish and provide corridors for wildlife movement (Pinkham, 2000). Pinkham (2000) also has a number of examples of improvements for wildlife, including spawning redds and increase in cutthroat trout in Jolly Giant Creek, California. Pinkham also found the return of frogs and garter snakes, habitat for crayfish, damselflies, and other macroinvertebrates as well as the increase in birds such as night herons, snowy and great egrets, towhees, doves and Anna's hummingbirds in Codornices Creek, California.

6.1.6 Managing Flood Events

6.1.6.1 Pre-Event Measures: to ensure that people and stakeholders are prepared, mitigate negative impacts, and facilitate efficient management of the event.

6.1.6.1.1 Flood-preparedness planning: major incident plans for flooding

6.1.6.1.2 Flood-risk mapping

6.1.6.1.3 Education and awareness-raising

6.1.6.1.4 Family/community flood plans,Flood risk logbooks

No information found. Their impact on biodiversity is probably negligible, although if floodplains are zoned, so development close to rivers is excluded then biodiversity could benefit.

6.1.6.1.5 Forecasting and Warning: to provide sufficient time for people and organisations to take effective mitigating actions prior flood water

6.1.6.1.6 Flood-forecasting systems: improved sensing, forecasting, modelling, and updating of model predictions during the event

No information found.

6.1.6.2 Warning dissemination systems arriving (including take-up)

Mitigation measure: Not applicable.
Adaptation measure: Improve accuracy of forecasts and increase time for action, thus reducing human risk.
Impact on biodiversity: None foreseen.

6.1.6.3 Flood Fighting: to manage floodwaters and defences during the event

6.1.6.3.1 Demountable/temporary defences

Mitigation measure: Not applicable.
Adaptation measure: Hold back or deflect floodwater from properties or transport networks to decrease damage or disruption. This may involve usage of flood storage areas such as wetlands and washlands (see 6.1.4.2.2) and detention ponds (6.1.5.1.3)
Impact on biodiversity: The defences themselves probably have minimal impact, but for the impacts of the deflected/stored water see relevant sections above. The frequency and duration of storage area use and the depth of water will affect the impacts on biodiversity, with longer times being detrimental (see introduction).

6.1.6.3.2 Water-level control structures: controllable weirs and sluices

Mitigation measure: Not applicable.
Adaptation measure: Control pathway of flow e.g. through diverting floodwater to storage areas and amount of river flow, through changing water levels.
Impact on biodiversity: The structures themselves can impede movement of fish. Indirectly the storage of water could be positive or negative (see for example flood storage areas such as wetlands and washlands (see 6.1.4.2.2) and detention ponds (6.1.5.1.3) and effects of flow levels.

6.1.6.3.3 Emergency repair/shoring-up of failing defences

No information found.

6.1.6.3.4 Emergency diversions: cut-through channels, breaking of dikes

Mitigation measure: Not applicable.
Adaptation measure: Reduce pressure on existing defences through use of planned and unplanned cuts diverting floodwater elsewhere.
Impact on biodiversity: Positive or negative, depends on to where water is diverted, but no definitive information.

6.1.6.4 Collective Damage avoidance actions: organised or spontaneous removal of people, assets or livestock to a safe location

6.1.6.4.1 Demountable flood defences

No information found.

6.1.6.5 Individual Damage

6.1.6.5.1 Avoidance Actions: actions taken by individuals to reduce flood losses including preventing or delaying flood water from entering buildings and moving people and assets.

6.1.6.5.2 Temporary floodproofing

6.1.6.5.3 Moving assets to safety

No information found.

6.1.7 Managing Flood Losses

6.1.7.1 Land-Use Management: Reduce current exposure to flood loss associated with existing developments

6.1.7.1.1 Managed retreat

No information found for rivers, but see coastal sections (6.2.4.1) and realignment of coastal defences (6.2.4.2)

6.1.7.1.2 Relocation of exposed structures

6.1.7.1.3 Flood-Proofing: reduce current exposure to flood loss through improved flood resilience

6.1.7.1.4 Retrofitted floodproofing

No information found.

6.1.7.2 Land-Use Planning: limit increase in exposure to flood loss associated with new developments

6.1.7.2.1 Land-Use planning (See Chapter 5)

6.1.7.2.2 Financial instruments: e.g. floodplain charging

6.1.7.2.3 Locate critical facilities away from floodplain

No information found.

6.1.7.2.4 Building Codes: limit increase in exposure to flood loss through changing building codes and/or construction practices

6.1.7.2.5 Floodproofing

6.1.7.2.6 Property/structure design standards

No information found.

6.1.7.3 Insurance, Shared Risk and Compensation: facilitate economic and financial recovery from flood loss

6.1.7.3.1 Insurance State aid/compensation

6.1.7.3.2 Tax relief on losses

1.7.3.2.a Public relief

1.7.3.2.b Self-insurance

No information found.

6.1.7.4 Health and Social Measures

6.1.7.4.1 Targeted health and counselling services

Mitigation measure: Not applicable.
Adaptation measure: Lessen health and social impacts of flooding.
Impact on biodiversity: Negligible.

6.1.7.4.2 Practical aid (clean up etc)

Mitigation measure: Not applicable.
Adaptation measure: Lessen practical impacts of flooding.
Impact on biodiversity: Possible negative effects of clean up operations if

chemicals are used, but no specific information found.

6.1.8 River Engineering

6.1.8.1 River Conveyance: alter river channel to increase conveyance of flow passed downstream

6.1.8.1.1 Channelisation

Mitigation measure: Not applicable.
Adaptation measure: Increase hydraulic capacity of existing channels by altering their hydraulic geometry and removing excess vegetation.
Impact on biodiversity: Negative. This can disconnect wetlands from important sources of water and lead to effective habitat fragmentation. On the Kissimmee River (US), loss of wetland habitat following channelisation has led to a 92% decrease in the use of the river floodplain by wintering waterfowl, with naturalised cattle egret having replaced a complex of wading birds, game fish have declined, as well as other species associated with slower flowing water (Toth et al., 1998).

Reduced fish abundance has also been noted (Cowx et al., 1986; Portt et al., 1986; Muotka and Laasonen, 2002). A comparison of fish populations in two "old channelized" sites, a downstream "partially channelized" site and an unmodified site showed that habitat diversity was low at the former (Swales, 1988). Fish community diversity was low at all sites, but relative species composition varied between sites, with two running-water cyprinids, dace *Leuciscus leuciscus* (L.) and chub *Leuciscus cephalus* (L.), being the dominant fish species. The former predominated at the "old channelized" sites. The conclusion of the study is that long-term river maintenance and management works may delay the morphological and biological recovery of lowland channelised rivers. Increased flow rates may remove gravel from spawning beds through scour, and any subsequent lack of gravel recharge and smothering of spawning grounds with fine sediments could have a marked deleterious impact on salmon productivity (Evans et al., 2004b). This would have a consequent impact on juvenile recruitment.

6.1.8.1.2 Channel restoration

Mitigation measure: Not applicable.
Adaptation measure: Restoration of more natural functioning of the river channel e.g. increase sinuosity and channel length.
Impact on biodiversity: Positive. Klein et al (2007) showed an improvement in the quantity, quality and diversity of in-stream habitat and spawning substrate as well as bird population numbers and diversity. Allowing channel migration can lead to vegetation succession being periodically interrupted, creating suitable sites for the regeneration of early successional species (Hughes, 1997).

6.1.8.1.3 Dikes and embankments

Mitigation measure: Not applicable.
Adaptation measure: Set-back or removal of embankments to increase on-line storage and reduced peak stage (Morris et al., 2004).
Impact on biodiversity: Positive and negative. Increased bank stability can reduce habitat heterogeneity and thus species diversity. The importance of this heterogeneity has been shown, for example, for algae (Passy and Blanchet, 2007), diatoms (Passy, 2001), macroinvertebrates (Beisel et al., 2000), insects (Brown, 2003) and juvenile salmon (Dolinsek et al., 2007). Embankments also accelerate sedimentation and promote the transformation of aquatic into terrestrial ecosystems (Buijse et al., 2002). Storage may benefit wetland ecosystems.

6.1.8.1.4 Bypass channels/flood-diversion channels

Mitigation measure: Not applicable.
Adaptation measure: Opening up old channels or creating new channels on the floodplain to slow runoff times.
Impact on biodiversity: The construction of diversion structures may disrupt vegetation and may adversely affect aquatic flora and fauna through altering flow patterns and flooding regimes. The use of green rivers (areas of former river valleys and backswamp areas that are dry for most of the year, but have a high probability of flooding) have been advocated in the Netherlands and biodiversity may be left undisturbed in these areas or can be managed to steer the course of vegetation development, such that under-represented habitat types or species can be favoured (Vis et al., 2003). Indirectly, the retention of runoff may contribute to biodiversity and ecosystem restoration by reducing erosion and retaining water on the land surface.

6.1.8.2 Engineered Flood Storage: construct or expand reservoirs, bunds or other impounding structures to increase flood storage

6.1.8.2.1 Dams (see Chapter 4)

Mitigation measure: Not applicable.
Adaptation measure: Control volume and timings of flow. They may reduce the variability of flow (although not necessarily in large HEP schemes)
Impact on biodiversity: Negative for native species. Reduced variability in flow decreases habitat heterogeneity and reduces native fish diversity, but increases invasive game and fish species (Leroy Poff et al., 2007). Cold water immediately below a dam may be beneficial for Salmonidae fish (Moyle and Mount, 2007). During dam construction invertebrate diversity and abundance decreases (Boon, 1988). Longer term alterations in community structure (which usually extend for a relatively short distance downstream) reflect changes in flow, substrate, temperature and water quality.

Dams also lead to extensive longitudinal and lateral fragmentation of river corridors, (Nilsson et al., 2005) thus hindering or preventing the migration of fish. Flow regulation by dams is often compounded by other modifications such as levee construction and normally results in reduced connectivity and altered successional trajectories in downstream reaches (Ward and Stanford, 1995). Flood peaks are typically reduced by river regulation, which reduces the frequency and extent of floodplain inundation. A reduction in channel-forming flows reduces channel migration, an important phenomenon in maintaining high levels of habitat diversity across floodplains. The seasonal timing of floods may be shifted by flow regulation, with major ramifications for aquatic and terrestrial biota. The truncation of sediment transport may result in channel degradation for many kilometres downstream from a dam. Deepening of the channel lowers the water-table, which affects riparian vegetation dynamics and reduces the effective base level of tributaries, resulting in rejuvenation and erosion. Ecological integrity in floodplain rivers is based in part on a diversity of water bodies with differing degrees of connectivity with the main river channel. Collectively, these water bodies occupy a wide range of successional stages, thereby forming a mosaic of habitat patches across the floodplain. This diversity is maintained by a balance between the trend toward terrestrialisation and flow disturbances that renew connectivity and reset successional sequences. Upstream of the dam, if water levels are increased, there maybe an increase in open water and marsh habitats (Toth, 1998).

6.1.8.2.2 Floodplain/wetland storage

Mitigation measure: Limited carbon sequestration, but also could lead to release of methane through anaerobic decomposition.
Adaptation measure: Increased rural storage of flood water.
Impact on biodiversity: Positive and negative. Widening of flood plains could provide significant areas of replacement of freshwater habitats and grazing marshes (Evans et al., 2004a) helping to offset losses at the g flooding is important for yellow wagtail breeding territories (Motacilla flava flavissima) (Bradbury and Bradter, 2004).

6.1.8.2.3 Floodplain restoration - similar to other restoration measures discussed earlier e.g. Riparian and floodplains 6.1.4.2.3

Mitigation measure: Limited carbon sequestration, but also could lead to release of methane through anaerobic decomposition.
Adaptation measure: Increased storage area for flood water. There is limited benefit from individual schemes, as areas are often small (Wade et al, 2004).
Impact on biodiversity: Can be positive. To maximise the biodiversity benefits, seasonal, frequent, low level inundation is required, along with high groundwater levels during the summer (Wade et al, 2004).

6.1.8.2.4 Temporary channel storage

No information found.

6.1.8.2.5 Flood Water Transfer: construct pipes or channels to convey flood waters to an adjacent catchment or drainage system

6.1.8.2.6 Pumped diversions to storage areas

No information found.

6.1.8.3 River Defences: construct or raise linear embankments and build or enhance control structures to contain and prevent floodwater from entering and manage flood waters specific areas

6.1.8.3.1 Flood defence along the river channel

Mitigation measure: Not applicable.
Adaptation measure: Bank protection or embankments to prevent flooding of adjacent land. These may need to be raised in the context of climate change, for example, around the Thames Barrier.
Impact on biodiversity: Bank protection may lead to loss of marginal habitats, but if reeds are planted or willow spiling used, then some marginal habitat albeit of a different nature may be maintained (Falconer and Goodwin, 1994).

6.1.8.3.2 Ring dikes around vulnerable areas

Mitigation measure: Not applicable.
Adaptation measure: Ensuring flood protection of particular areas under high runoff conditions. In the Netherlands, a dike-ring is a geographical area bounded by dikes and under the Water Embankment Act (1995) it should be protected against floods of a given magnitude (Aerts et al., 2008).
Impact on biodiversity: No information, but they may be associated with the construction of some temporary storage areas.

6.1.8.3.3 Specialist structures such as floodgates

Mitigation measure: Not applicable.
Adaptation measure: Prevent flood water entering specific areas where permanent structures would be visually intrusive or prevent bank access and. control of timing and location of flows.
Impact on biodiversity: Negative - as for dams (Chapter 6.1.8.2.1) and other structures. These create interruption of species' movements, especially migratory fish within the river and the transfer of fish to natural lakes on the flood plain (von Lany and Palmer, 2007). A survey of coastal streams in two areas in New Zealand found that of 209 structures, 33% had a high potential to restrict fish passage at some or all flow conditions (James, 2006). In Lake Wairarapa, New Zealand, a reduction in the variation in water levels, especially the shorter periods of flooding and drying, has encouraged a community of marsh turf plants to develop on the eastern shore, presumably providing a better habitat for invertebrates and hence the increased wader numbers (Robertson and Heather, 1999).

6.2 Coastal flood management

Climate change will directly impact the physical, chemical and biological nature of the oceans, as well as the interactions between them. A review of these is provided by Harley et al. (2006), including some non-independent effects, which highlight the complexity of the impacts of climate change. This report is focused on how changes in projected temporary coastal flooding rather than sea-level rise could impact on biodiversity. Coasts, like rivers are dynamic systems where low-lying areas are prone to flooding and it can be difficult to identify the drivers and impacts of climate change (Nicholls, 2007). In the 20th century, global sea level rise has contributed to higher flood levels, and erosion, but the main effect on ecosystems has been direct and indirect human destruction (Hoozemans et al., 1993; Coleman et al., 2008), compensated for in places by habitat restoration. Earlier destruction of protective ecosystems, such as inter-tidal habitats, has amplified the need for coastal flood management. Some of this is being addressed through the EC Habitats Directive, as many coastal habitats, such as dunes, mudflats and Atlantic salt meadows, have been listed and thus should be protected by Member States though a network of sites.

In densely-populated coastal areas, such as Europe, coastal ecosystems can be highly vulnerable to sea-level rise, and that vulnerability is exacerbated by coastal squeeze where human assets are protected by infrastructure that limits onshore migration (Nicholls and Klein, 2005;(Rochelle-Newall et al., 2005). There is very high confidence that future climate change will lead to increasing coastal risks through associated sea level rise; storm intensification, larger extreme waves and storm surges may also be important but this is less certain (Nicholls et al., 2007). Where inland migration is prevented (naturally or artificially) ecosystems are especially vulnerable to decline.

6.2.1 Ecological effects of coastal flooding

Sea-level rise will generally lead to increasing salinity in estuarine systems, resulting in the displacement of existing coastal communities inland. Many of the impacts of coastal floods are similar to those for river floods, except that the water is saline and this can have implications when it reaches brackish and freshwater habitats, such as mangroves, estuaries, deltas and flood plain grazing marshes, where species also may be displaced inland (Nicholls et al., 2007). Conversely, an intensified hydrological cycle, with consequent changes in runoff could reduce salinity and thus there are competing trends. Increased freshwater inflows decrease water residence time and increase vertical stratification, and vice versa (Moore et al., 1997). The effects of altered residence times can have significant effects on phytoplankton populations, which can increase fourfold per day. In estuaries with very short water residence times, phytoplankton are generally flushed from the system as fast as they can grow, reducing susceptibility to eutrophication and harmful algal blooms. Changes in the timing of freshwater delivery to estuaries could lead to a decoupling of the juvenile phases of many estuarine and marine fishery species from the available nursery habitat. Salinity gradients are very important in determining ecosystems and there is evidence that non-linear responses may occur as critical thresholds of inundation and salinity are exceeded (Burkett et al., 2005).

6.2.2 Coastal flood management and mitigation

Larger scale measures, such as coastal wetland restoration, may contribute to climate change mitigation, as wetlands can act as buffers against floods, especially wave action (Brampton, 1992; Möller et al., 2001), and significantly contribute to carbon sequestration as they trap carbon without producing methane (Chmura et al., 2003; Trulio et al., 2007) Brigham et al., 2006. For example “Estuarine wetlands sequester carbon at a rate about 10-fold higher on an area basis than any other wetland ecosystem due to high sedimentation rates, high soil carbon content, and constant burial due to sea level rise” (Brigham et al., 2006, p902). Unlike other wetlands they emit negligible amounts of greenhouse gases (Chmura et al., 2003); thus, they could be more valuable as carbon sinks than any other ecosystem in a warmer world (Choi and Wang, 2004).

6.2.3 Coastal flood management and adaptation

Coastal ecosystems are currently under pressures from a variety of drivers and these already adversely affect the integrity of coastal ecosystems and thereby their ability to cope with any additional strains, including climate change and sea-level rise, which could lead to an increased risk of flooding. In coastal areas, as in many other sectors, adaptation will provide immediate and longer-term reductions in risk (Nicholls et al., 2007). Coasts are also impacted by adaptation in other sectors including river flood management, while loss of sediment supply due to dams, cliff protection, alterations in tidal flow patterns, navigation and flood control works can have large effects on coastal processes and largely negative effects on habitats.

Various classifications of the approaches to manage coastal floods and other hazards have been suggested. Here, in addition to the Foresight approach, one widely- and long-used classification comprises: (1) protection, (2) accommodation and (3) retreat (Nicholls and Klein, 2005). Protection reduces the risk of flooding and erosion by means of hard or soft defences and also prevents the onshore migration of coastal ecosystems, promoting ‘coastal squeeze’. Accommodation reduces the impacts of flooding and erosion by changing land use and building design. (Planned) retreat reduces risk by limiting potential effects and/or removing assets from the areas threatened by flooding and erosion. These measures often form part of Integrated Coastal Zone Management (ICZM) strategies where often they are applied in combination and interaction may occur between them, e.g. retreat may lead to sediment supply continuing along the coast thus diminishing or removing the need for (additional) intervention at downdrift locations. Here, we mainly follow the Foresight approach for consistency with river flood management, although accommodation measures are included for completeness.

6.2.4 Coastal Engineering

6.2.4.1 Coastal Defences: construct or raise physical barriers to flooding and coastal erosion

6.2.4.1.1 Flood barriers

Mitigation measure: Not applicable.
Adaptation measure: Physical structures control timing and location of flows during flood events, with consequences for water quality (salinity).
Impact on biodiversity: This will depend on the frequency of closure which is likely to increase as sea levels rise, similar to 6.1.18.2. Floodgates on drains to prevent tidal and partial flood ingress into drained coastal areas and permit the drainage of land to mean low tide level can lead to the oxidation of acid sulphate soils and the death of biota and community change (White et al., 1999). Fish community structure above and below tidal barriers to estuarine wetlands can vary considerably, depending on the degree of tidal exchange, but highly modified habitats can still be used by fish as juvenile nursery areas, provided they have sufficient water area and productivity (Gibbs et al., 1999). The development of stable faunal communities above structures can significantly enhance biodiversity conservation.

6.2.4.1.2 Dikes and embankments

Coastal defences, especially for protection against erosion, often involve low crested structures (LCSs), which may overtop under extreme conditions. They are frequently combined with soft protection measures, such as beach nourishment schemes (Lamberti et al., 2005), which are dealt with in section 6.2.4.4.1.

Mitigation measure: Not applicable.
Adaptation measure: Construction or raising of hard defences such as breakwaters, groynes, seawalls, dykes or other rock-armoured structures to reduce probability of flooding.
Impact on biodiversity: General impacts on biodiversity are summarised in Table 6.1, which suggests that the impact may depend on the spatial and temporal scale under consideration. The context may be important too as in some areas, such as the southern North Sea, hard structures add a habitat to otherwise soft shores. A study of climate change impacts on intertidal habitat at five sites in the US projected severe losses at four sites and that the most severe losses were likely where the coastline is unable to move inland because of steep topography or seawalls (Galbraith et al., 2002). This would have important implications for shorebirds in these locations.

The effects of LCS have been particularly investigated by the DELOS project, in which Moschella et al. (2005) found that artificial hard substrates are generally colonised by biota that were found in nearby rocky shores, coastal lagoons or on other artificial structures. Impacts can be context dependent, e.g. in coastal sandy habitats, local biodiversity may increase through the presence of opportunistic species (generally on the landward side), as well as the accidental presence of hard-bottom species (e.g. mussels and crabs) in the soft bottoms (Airoldi et al., 2005; Bulleri, 2005). The LCS also seem to provide particularly suitable habitat for new settlers, juvenile fish (particularly non-commercially important fish) and other mobile fauna and the enhanced settlement of fish and crustaceans seems to occur especially in the presence of accumulations of drifting algae (Martin et al., 2005). The resulting changes in species composition, abundance and diversity can have important consequences for the functioning of coastal ecosystems, modifying productivity and nutrient cycling (Loreau et al., 2002). A high number of nearby artificial structures can act as stepping stones, disrupting natural barriers and facilitating the dispersal of rocky coast species across habitats and regions that naturally would be poorly connected.

Table 6.3: Summary of the main impacts expected from the construction of hard defence structures with respect to the "do nothing" alternative, and their relevant spatial and temporal scales (modified from Airoldi et al., 2005).

Factor	Spatial scale	Temporal scale	Direction of change	Predictability
Water quality	Local	Short to medium	↓	**
Soft-bottom habitats	Local	Short	↓	***
	Regional	Medium	↓	***
Soft-bottom species richness	Local	Short to medium	↑↓	**
	Regional	Long	↑↓	*
Hard-bottom substrata	Local	Short	↑	***
	Regional	Medium to long	↑	***
Hard-bottom species richness	Local	Short to medium	↑	***
	Regional	Long	↑↓	*
Fish and mobile fauna	Local	Short to medium	↑	***
	Regional	Long	↑↓	*

Factor	Spatial scale	Temporal scale	Direction of change	Predictability
Productivity	Local	Short to medium	↑	**
	Regional	Medium to long	↑↓	*
Ephemeral and nuisance species	Local	Short to medium	↑	***
Non-native species	Regional	Medium to long	↑	**
Dispersal barriers	Regional	Medium to long	↓	*
Habitat fragmentation	Regional	Medium to long	↑	*

Both direction of change (↑ = increase, ↓ = decrease, ↑↓ = not known) and estimates of the current ability to make predictions (* = low, ** = moderate, *** = good) are indicated.

An increased connectivity between natural rocky reefs can increase the gene flow within a species (Palumbi, 2003). This can be negative since it can reduce local adaptation within a species and thus, on a larger time scale, decrease the evolution of new species. The system of artificial structures can also provide new dispersal routes that permit the invasion of non-indigenous species, including pests (Bulleri and Airoldi, 2005). Coastal defence structures can also affect surrounding soft-bottomed environments and biota more indirectly through modification of water flow, sediment characteristics and predation. LCS generally are a relatively poor surrogate for natural rocky shores, as Moschella et al. (2005) found that epibiotic assemblages were less diverse and provided less structurally complex habitats for colonisation and in some locations experienced higher disturbance than natural shores. Recommendations for more environmentally sensitive construction is given in Airoldi et al. (2005) and Moschella et al. (2005).

6.2.4.2 Realignment of Coastal Defences: relocation landwards

6.2.4.2.1 Change configuration of coastline (planned)

Mitigation measure: Increase coastal wetland area.
Adaptation measure: Realignment includes the deliberate breaching of seawalls or summer dikes (de-embankment) or regulated tidal exchange and promotes the creation of intertidal habitat, particularly salt marsh and mudflats, but it can be applied to shingle ridges and dunes (French, 2001; Pontee, 2007; Rupp-Armstrong and Nicholls, 2007). Removing or realigning coastal defences or

allowing natural features to move landwards can increase the inter-tidal area, thus attenuating tidal and especially wave energy. This may lead to lower landward defences if they are required (Evans et al., 2004b). In tropical areas it could include the extension of mangroves, although no examples are known to date.
Impact on biodiversity: Positive and negative. Atkinson et al. (2001) provide a summary of the results of invertebrate and some fish monitoring data from realignment sites around the world (Table 4-3) and a comparative study of bird usage at two managed retreat sites in the UK (Appendix). All indicate the significant time lag of responses involved in the re-establishment of biodiversity.

Positive impacts occur through landward migration of habitats e.g. salt marsh and beaches, but this may squeeze coastal grazing marsh and freshwater habitats. Several schemes in the UK aimed at enhancing flood defences and increasing areas of inter-tidal habitat are given in Pontee (2007). This habitat increase could lead to gains in supporting specialist plants, invertebrates and molluscs, bird roosting and feeding areas, and expansion of fish nurseries (Dixon et al., 1998). A study of salt marsh restoration following managed realignment on 70 sites showed that many sites contain less than 50% of the regional target species (all species with the potential to establish in a salt-marsh restoration site in the region, if the site were suitable and accessible), especially when sites are smaller than 30 ha (Wolters et al., 2005). Higher species diversity is observed for sites exceeding 100 ha and for sites with the largest elevational range within mean high water neap to mean high water spring tide, while most sites less than 20 years old contain more target species than older sites.

Banked realignment schemes can create habitats with greater physical and biological connectivity with the wider estuary, e.g. at Welwick in the Humber Estuary, UK with the wholesale removal of the fronting flood embankment rather than the creation of breaches to create a compensatory mudflat habitat (Pontee et al., 2006). Movement of structures and natural areas inland could, however, have negative consequences for other coastal species and habitats. Coupled with sea-level rise and topography, mud flats may become the dominant inter-tidal habitat at the expense of salt marsh (unless the sites are artificially raised) and, on the landward side, coastal grazing marsh and salt lagoons may be lost (e.g. see Gardiner et al., 2007). Habitat recreation/relocation may be an option, but often there are constraints posed by development and availability of suitable sites. Fluvial grazing marsh could be created artificially in neighbouring catchment areas as compensatory habitat, but this raises important scientific and policy questions such as its acceptability and the interpretation of designations within the EC Habitats Directive (Gardiner et al., 2007). Increasing the inter-tidal area will enlarge the fauna, bird feeding and fish nursery areas (Evans et al., 2004b) and the feeding grounds of some non-breeding water birds, especially waders (Atkinson et al., 2001; Crowther, 2007).

Managed realignment in urban areas can be more difficult in finding suitable sites, but the realignment of a 130 m length of defences inland by 10 m along the Greenwich Peninsula near the Millennium Dome, London, created additional intertidal habitat, a salt marsh area and habitats for estuarine animals and plants, e.g. common reed (Phragmites australis), sea aster (Aster tripolium) and sea club-rush (Bolboschoenus maritimus) (Shih and Nicholls, 2007). The Thames estuary above the barrier could offer the opportunity to create new (or compensatory) intertidal habitats. Urban realignment is aimed at (1) enhancing flood defence, (2) improving public recreation and access, and (3) creating intertidal habitats (Shih and Nicholls, 2007), and while it is not always possible for a scheme to realise all these objectives it does show how there could be cross-sectoral benefits.

Realignment may lead to secondary negative effects on biodiversity – directly due to loss of terrestrial and freshwater habitats, particularly coastal grazing marsh (Lee, 2001; Nicholls and Wilson, 2001); indirectly through the remobilization of stored pollutants (Blackwell et al., 2004), the eutrophication of estuarine waters due to nutrient release (MacLeod et al., 1999; Blackwell et al., 2004) or saline intrusion into adjacent water tables.

6.2.4.3 Abandonment (managed or unmanaged) of Flood Defences: unmanaged realignment

6.2.4.3.1 Change configuration of coastline (often unplanned)

Mitigation measure: Same as Flood barriers (section 6.2.4.1.1)
Adaptation measure: Same as 6.2.4.1.1, except this will often happen in an unplanned manner with much less design and retreat is unlikely to be to a new defence line – rather an entire flood compartment will be abandoned.
Impact on biodiversity: Same as 6.2.4.1.1, except that as much of this is unplanned mudflats are much more likely than salt marshes, and issues such as compensatory habitats for lost habitats, such as coastal grazing marsh, are less likely to addressed.

6.2.4.4 Reduce Coastal Energy: structures, features or devices to reduce the energy of near-shore waves and currents

6.2.4.4.1 Beach nourishment

Mitigation measure: Not applicable.
Adaptation measure: Beach manipulation (BM) involves various soft structural stabilization techniques, including: beach nourishment, beach bulldozing (beach scraping), dune creation (including sea grass planting), restoration and reshaping, which are often used in conjunction with each other to combat coastal erosion (Greene, 2002). It can also involve the landward movement of

other (hard) coastal defences. Removing or realigning coastal defences or allowing natural features to move landwards can increase the inter-tidal area, thus attenuating wave and tidal energy (Evans et al., 2004b). Beach nourishment involves sediments from a dredge site or terrestrial source being added to a beach to elevate and extend it seaward. This can dissipate wave energy, protecting the inland and reducing further erosion. The impacts on both the mined area and the receiving site need consideration. Salt marshes can also be used to increase surface roughness to dissipate wave energy (Evans et al., 2004b).
Impact on biodiversity: Generally negative, especially in the short-term, but there are some positives. Beach nourishment (BN) initially can result in the smothering of shallow reefs, all species and the degradation of beach habitats (Peterson and Bishop, 2005). It can lead, at least in the short-term, to a decrease in species diversity and changed species composition on adjacent beaches (Reilly Jr and Bellis, 1983) as well as reduced densities of invertebrate prey for shorebirds, surf fishes (Wilber et al., 2003) and crabs (Peterson and Manning, 2001; Peterson and Bishop, 2005). It has been shown to decrease nesting frequency (by 4.4 to 5.4 nests km^{-1} day^{-1}) and false crawl frequency (by 5.0 to 5.6 FC km^{-1} day^{-1}) of Loggerhead sea turtles (Caretta caretta) during the first season following beach nourishment, but the effect was much reduced in the second season (Rumbold et al., 2001). Beach nourishment can benefit endangered and threatened sea turtles (Nelson, 1991) and some nesting shore birds by restoring habitat along eroded beaches. Other studies have shown little or no long-term effect (e.g. on benthic fauna; Culter and Mahadevan, 1982). It has been suggested that the sediment grade used for beach fill influences the extent of impact and recovery for the intertidal beach macrofauna and thus their availability for feeding surf fishes and resident and migratory shorebirds (Greene et al., 2002).

Dredging for sediment for beach nourishment leads to direct mortality of the benthic fauna that live in the substrate and possibly marine mammals through collisions with dredging equipment. Physical changes to the seafloor geomorphology may reduce the ability of benthic flora and fauna to adapt to the new conditions, for example crustaceans may be replaced by polychaete worms, albeit maybe only temporarily (in Greene et al., 2002). There is debate about the rate and amount of recovery from mine sites, but in general, areas where biological impacts are greatest and most prolonged are those where bottom sediment composition has been altered. Impacts to benthic organisms at the target beach are generally considered to be less than those that affect benthic organisms at the mine site. This is likely due to the fact that organisms living in the high-energy beach environment, especially the intertidal area, may be better adapted to disturbances (Van Dolah et al., 1994; Levison and Van Dolah, 1996).

There is considerable uncertainty about biological impacts of BM, possibly due to the poor quality of monitoring studies (Peterson and Bishop, 2005), but a good review is provided by Greene (2002). Recovery from any bulldozing generally seems fast (within months); although mole crabs and ghost crabs seem to take longer (Peterson et al., 2000).

6.2.4.4.2 Offshore barriers

Mitigation measure: Not applicable.
Adaptation measure: Dissipation of wave energy through physically blocking or modifying the incoming energy at some distance seaward of the shoreline, e.g. through the use of laying mats with baffles in the inter-tidal or near shore sub-tidal zone, offshore breakwaters, submerged reefs, offshore tables mounted on piles that dissipate wave energy and fishtail groynes to divert the tidal flow away from the shore (Evans et al., 2004a).
Impact on biodiversity: Can be positive. They can results in the build-up of sand and shingle habitats, the latter being of botanical importance and support nesting populations of bird species of conservation concern such as Little Tern (Sterna albifrons) (Evans et al., 2004a).

6.2.4.4.3 Energy converters

Mitigation measure: Not applicable, unless also coupled with energy production (Chapter 4).
Adaptation measure: Tidal barrages or wave energy converters would reduce wave energy. Energy production and flood management is still at the research and development stage.
Impact on biodiversity: See Chapter 4.

6.2.4.4.4 Modify morphology (see 6.2.4.5)

6.2.4.5 Coastal Morphological Protection: allow or encourage changes in coastline to accommodate forcing processes

6.2.4.5.1 Promote formation of natural landforms to provide protection

Mitigation measure: Possible carbon sequestration with promotion of salt marsh.
Adaptation measure: Development, enhancement or re-creation of natural features, including salt marsh and dunes, and the creation of new tidal inlets to provide increase shoreline protection (Evans et al., 2004b). Offshore breakwaters and fishtail groynes also could be used to provide the coastal protection (see Offshore barriers - 6.2.4.4.2). This overall approach is still at the research and development stage.
Impact on biodiversity: Positive, in that it promotes natural processes and seeks to use coastal ecosystems as a means of protection, although as with realignment of defences some habitats such as coastal grazing marsh may be lost under this approach.

6.2.4.6 Accommodation

Accommodation as defined by Nicholls and Klein (2005) does not fit exactly into the above flood management categories, which are more linked to protection or retreat, and so is dealt with separately for completeness. Note that some of the earlier river flood management measures under Pre-Event Measures, Managing Flood Losses and Land-Use Management are using the principles of accommodation. To date, these approaches are not widely applied in Europe, but used extensively in other areas such as in the USA and Bangladesh where buildings are raised above flood levels on piles and flood warning systems indicate likely flood events.

Mitigation measure: Varies according to the adaptation measure. Afforestation would be positive for carbon sequestration, but is an unlikely measure in the European context.
Adaptation measure: Accommodation can take many forms including changes in land use (e.g. salt-tolerant crops, set aside and coastal afforestation), extensive flood-proofing or elevation of property, modification of urban drainage systems and raising of roads (see Bray et al., 1997; Klein et al., 2001).
Impact on biodiversity: The impacts of infrastructural changes are largely unknown, but unlike protection approaches, accommodation may allow wetland habitats to migrate onshore, countering coastal squeeze (Berry, 2007) or encourage the alteration of agricultural land into semi-natural habitats. Afforestation, e.g. with mangrove trees, has been suggested for Bangladesh (Ali, 1996). These would be neutral to positive for biodiversity, depending on circumstances.

6.3 Discussion

The previous two sections have shown that there are a great range of opportunities for adaptation to climate change-induced flooding and these have a variety both direct and indirect impacts on biodiversity (Table 6.2). While these methods have historically been developed for adaptation purposes, some of them have mitigation benefits as well. Under best management practice, only channelisation, dams and other specialist structures such as floodgates are thought to be negative for biodiversity, through, for example, their modification of flow regimes and the barrier they form to dispersal. Measures, such as afforestation, depend very much on the how they are implemented. All the other measures are at best neutral and nearly half of the river measures and more than half of the coastal measures can be highly beneficial for biodiversity. In many cases this is a consequence of the restoration of more natural ecosystem functioning and/or greater wetland habitat area. This was raised too by Watkinson et al. (2007b) who suggested that if many of the Foresight strategies were widely implemented, as opposed to maintain the historic focus on hard defences, there would be significant environmental changes which in some ways represented a reversion to pre-managed landscapes.

Strategy	Biodiversity Impact/		Habitats affected									Taxa affected						
	Impact under **inappropriate** use	Impact under **best** management practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland, forest and other wooded areas	Inland unvegetated or sparsely vegetated	Agricultural, horticultural and domestic	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants
Changing tillage practice (no till)	↘	↗									●	●	●	●	●	●	●
Extensification	⇔	↗					●				●	●	●	●	●	●	●
Field drainage	⇔	↗					●				●		●				●
Afforestation	↘	↗			●				●			●	●	●	●	●	●
Buffer strips and buffering zones	↗	↑			●		●				●	●		●			●
Detention ponds and bunds	↘	↑			●		●				●		●	●			●
Wetlands and washlands	↘	↑			●	●	●				●		●			●	●
Riparian and floodplain impoundments	↓	↗			●	●	●				●				●	●	●
Management of hill slope connectivity	↘	↗			●												
Drainage channel maintenance	↗	↑			●							●		●	●		●

Drainage channel realignment	↘	↑			•							•	•	•	•	•	•
Building design (for water storage)	↘	↑											•			•	•
Urban area development	↘	↗					•	•			•	•	•			•	•
Detention ponds	↓	↑				•									•	•	•
Stormwater source control	↘	↗			•	•							•				•
Rainwater harvesting	↘	⇔			•											•	
Building design (for infiltration) - green roofs	↗	↑			•								•			•	•
Reopen culverted watercourses	↗	↑			•							•	•	•	•	•	•
Demountable/temporary defences	↘	↗			•											•	•
Water-level control structures	↘	↗			•												•
Land-use planning	↓	↑			•		•		•		•	•	•	•			•
Channelisation	↓	↘			•								•		•		
Channel restoration	↗	↑			•								•				•
Dikes and embankments	↘	↑			•										•	•	•
Bypass channels/flood-diversion channels	↘	↗															

Dams	↘	↓			•										•	•	•
Floodplain/wetland storage	↘	↑			•								•				•
Floodplain restoration	↗	↑			•												
Flood defence along the river channel	↘	⇔			•												•
Specialist structures such as floodgates	↓	↘			•										•		
Coastal flood management																	
Flood barriers	↓	⇔															
Dikes and embankments	↘	↑	•	•											•	•	•
Beach manipulation	↘	⇔	•	•								•	•	•	•	•	•
Managed realignment	⇔	↑	•	•	•	•						•	•	•	•	•	•
Beach nourishment	⇔	↑	•	•								•	•		•	•	•
Offshore barriers	⇔	↑	•	•									•				
Energy converters	↘	⇔	•	•									•		•		
Modify morphology	⇔	↑	•	•													
Promote formation of natural landforms to provide protection	⇔	↑	•	•													•

Accommodation	↘	↑	•	•	•	•						•	•	•	•	•	•
Coastal protection	↓	↗	•	•								•	•	•	•	•	•

↑ Highly beneficial for biodiversity
↗ Moderately beneficial for biodiversity
⇔No known effect on biodiversity
↘ Moderately detrimental for biodiversity
↓ Highly detrimental for biodiversity

Table 6.4: Biodiversity Impact Table.

The table summarises the impact of each measure on biodiversity. It identifies the worst-case management scenario (e.g., a careless and inconsiderate adoption of a measure) and the best-case (e.g., following good practice); it also identifies the habitats and taxa affected. The arrows indicate the degree of impact:

The Foresight project considered the effects of various flood management measures under four socio-economic scenarios (World Markets, National Enterprise, Local Stewardship and Global Sustainability) and found that many of the more effective risk-reducing responses in fluvial and coastal zones appeared to have significant environmental and other penalties in more than one of the scenarios (Watkinson et al., 2007b). Coastal defences failed across all four scenarios while river defence, conveyance and engineered flood storage failed under the consumer-oriented scenarios. In contrast, other adaptation response strategies appeared both to reduce flood risk and to have environmental benefits (see Tables 26.1 and 26.2 in Watkinson et al., 2007b). These beneficial measures are catchment-wide storage along rivers, coastal defence re-alignment, land-use planning and morphological coastal protection. Catchment-wide storage along rivers and coastal defence re-alignment score consistently well under other criteria e.g. capital and ongoing costs. The manner of implementation of managed re-alignment, however, may be important in determining the environmental benefits (and realignment and especially morphological protection still require major development).

The river flood management measures all primarily impact on inland surface waters and to a lesser extent on mires and fens, grasslands and agricultural habitats, while the coastal measures primarily impact marine and coastal ecosystems. There are some possible feedbacks onto ecosystems, such as inland waters and mires and fens (Table 6.2). This illustrates the linkages between the river and coast. The taxa impacted vary, and in many cases knowledge is limited or non-existent and in the latter case the measures have been excluded from the table. In the Foresight project, the key environmental threats identified across the four scenarios were a decline of coastal grazing marsh (Watkinson et al., 2007b). Large net losses were expected due to a combination of planned re-alignment and unplanned coastal abandonment. They suggested that it is possible that the habitat could be replaced by more sympathetic management of inland grazing marshes and increased rural storage along rivers could provide significant areas of replacement of freshwater habitat and grazing marsh inland (Gardiner et al., 2007; Richards et al., 2008), although this will be challenging for the current interpretation of the EC Habitats Directive. Watkinson et al. (2007b) also argue that response strategies offer higher environmental benefits if implemented in a long-term, broad-scale co-ordinated and proactive manner.

Nearly all river and coastal flood measures do not involve mitigation, except indirectly where there is a promotion of change/creation of habitat, e.g. wetland storage and re-creation and coastal realignment and reconfiguration (Figure 6.1). Most of these impacts will be local, with only a small effect on mitigation. The major river flood control measure that has both a mitigation and adaptation component is large dams, where flood control and HEP production are among their objectives. These are largely negative for existing biodiversity, although there is considerable complexity in assessing the ecosystem effects (McAllister et al., 2000; McCartney et al., 2000). Globally there has been a slow down in the rate of building of large dams, with smaller schemes being more favoured. This could help to lessen the environmental impact as the magnitude of some of the changes is reduced, but given the debate about their contribution to mitigation too, large dams are generally considered to pose a high risk to biodiversity (Figure 6.2). Large dams, therefore, increasingly can be seen to represent a win as an adaptation for flooding, but more of a possible loss for mitigation and for biodiversity.

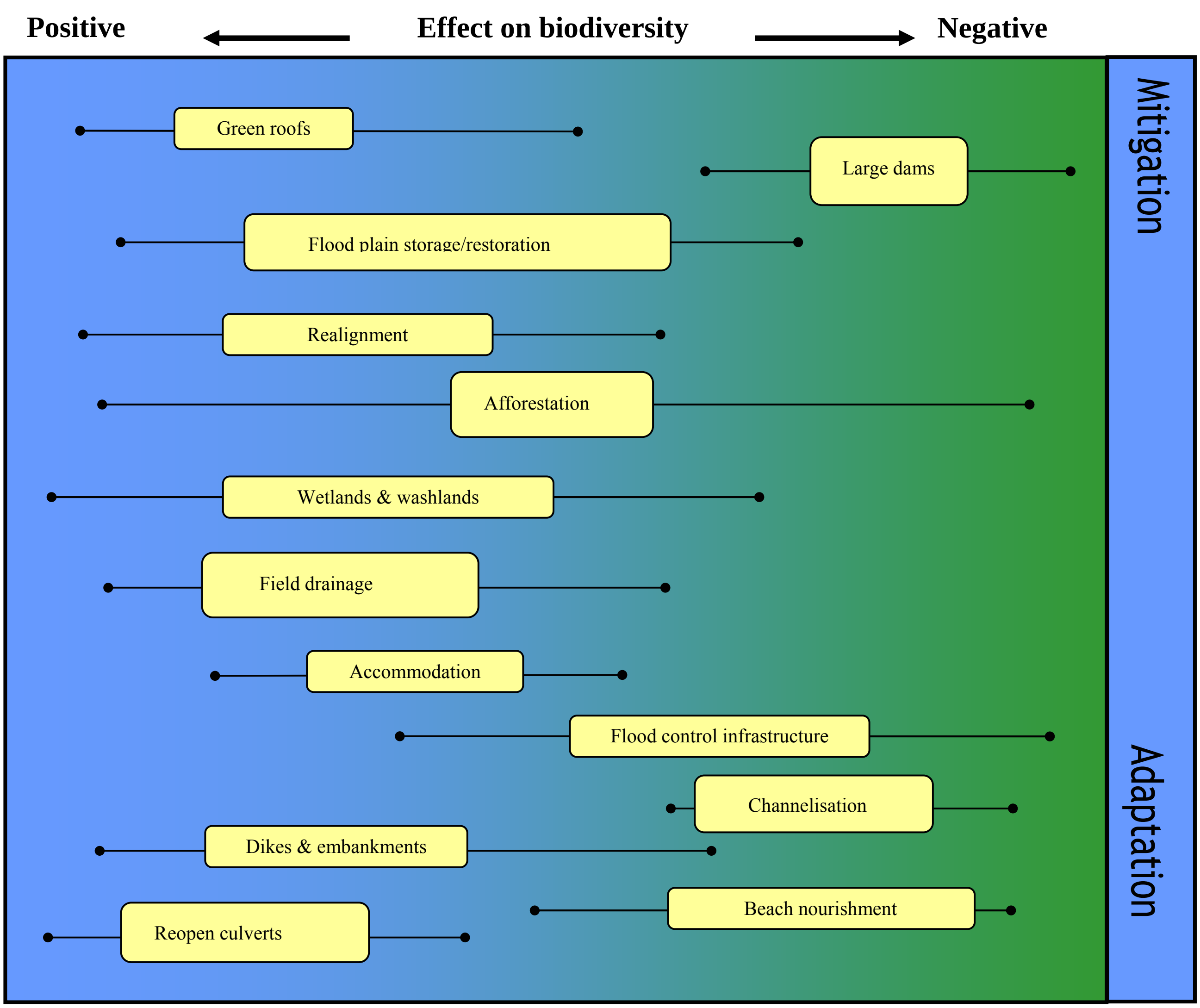
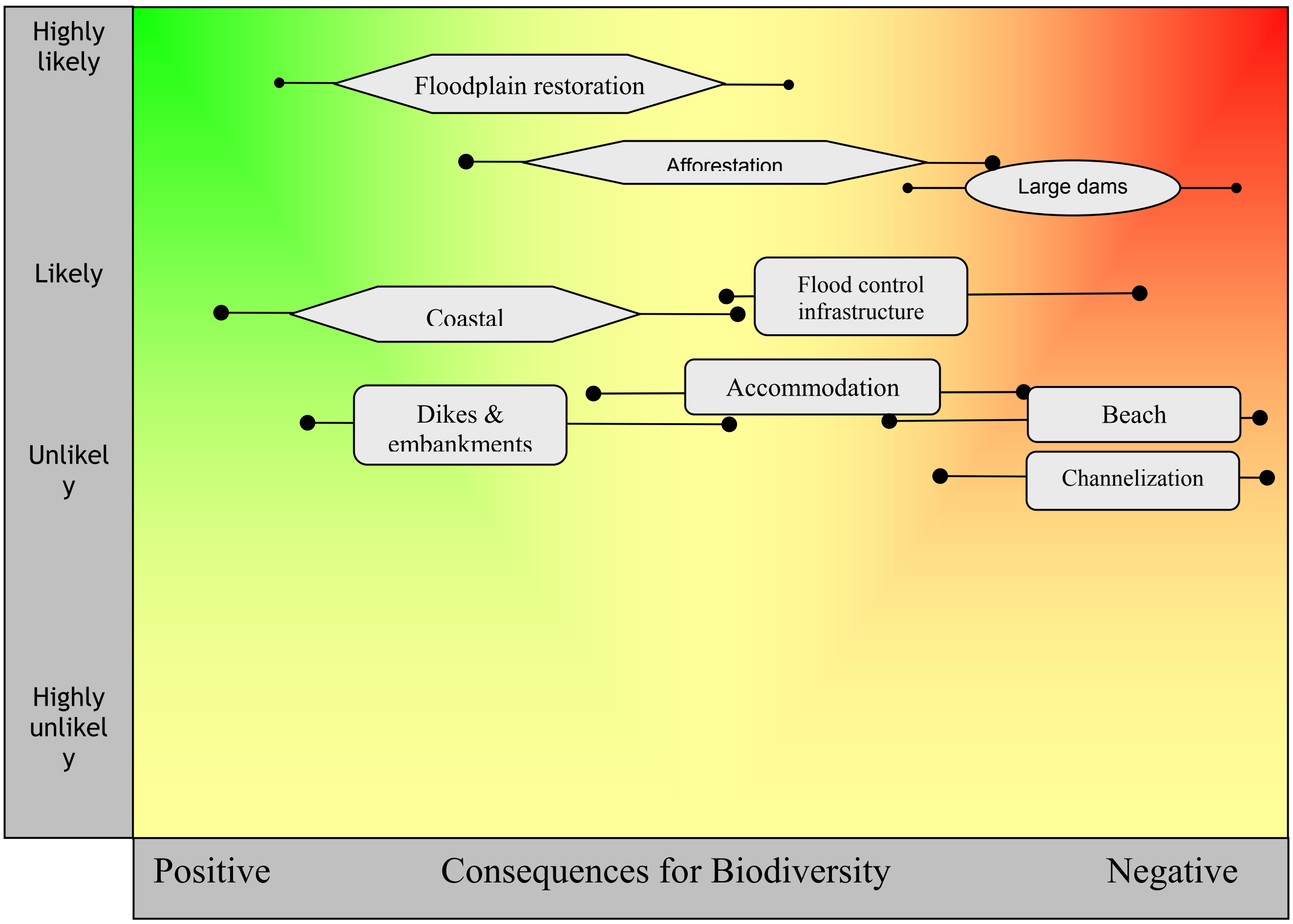


Figure 6.4: Known and potential relationships between river and coastal flood mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on a literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts.

All the other river and coastal flood management measures, for which there is a reasonable body of information, are primarily implemented as adaptation responses. Of these, flood control infrastructure, channelisation and beach nourishment are reckoned to be largely negative for biodiversity (Figure 6.1), with the former probably posing the biggest risk (Figure 6.2). Scale, however, may be important in affecting the degree of impact. The other measures have the potential to represent win-win situations for biodiversity in terms of adaptation and biodiversity and thus they do not pose a risk. Those which contain an incidental element of mitigation, such as flood plain storage and restoration represent low risk, win-win-win situations (Figures 6.1 and 6.2) and are strategies which should be promoted.



6.3.1 Cross-sectoral

There are also important cross-sectoral links for many of the measures as indicated by the cross-referencing to other chapters and as is discussed in Chapter 10. Only two examples will be briefly mentioned here. Most of the floodplain area is currently used for agriculture and as has been pointed out the use of washlands for flood management, conservation or other activities can involve economic losses; thus, trade-offs may need to be identified and a cost assessment carried out (Dickie, 2001). He provides some case studies of such analysis from the UK. Watkinson et al (2007b) suggest that where land is at a premium, e.g. in coastal areas, environmental trade-offs may have to be considered between floodplain and agricultural habitats.

In terms of the built environment, any measure that increases “green space” for flood management purposes, including green roofs, can also represent cross-sectoral win-win situations. Developing such cross-sectoral win-win situations is critical for effective use of resources, but also they should help in the promotion of conservation and the provision of flood regulation.

6.3.2 Links between rivers and coasts

In this report, rivers and coasts and their flood management measures have been considered separately, but in reality they form a continuum from the terrestrial to marine phase of the hydrological cycle. In addition, while these measures are considered individually, very often they are implemented as a part of a wider integrated package of river basin or coastal management, impacting each other; however, generally a single measure is not adequate to cover all situations or requirements. For instance, there is the potential of refocusing grazing marsh from coastal to fluvial locations.

Policy too is increasingly involving integration between them and the inclusion of biodiversity. The European Water Framework Directive (WFD), for example, aims to achieve good ecological and chemical status for surface water bodies and to introduce a holistic approach to water management. It applies to all surface freshwater bodies (including lakes, streams and rivers), groundwaters, groundwater dependent ecosystems, estuaries and coastal waters. Strategic guidance on managing the risks related to river flooding is provided by Catchment Flood Management Plans (CFMPs) and for coasts by Shoreline Management Plans (SMPs). These both help to support the implementation of the WFD. Successful implementation is seen as aiding the enhancement and protection of water quality and the wider environment by, amongst other things, improving associated wildlife habitats. Once again this highlights the importance of considering rivers and coasts together and the possibility of achieving both adaptation to flooding and biodiversity objectives. On coasts, integration across sectors, environmental values and administrative levels are provided by two more strategic documents: Estuary Management Plans (EMPs) and Coastal Zone Management Plans (CZMPs), but as these are non-statutory they could be seen as a problem for truly integrated coastal zone management (de la Vega-Leinert and Nicholls, 2008).

6.4 Conclusions

This study is one of the few to consider river and coastal flood management measures together and the first to comprehensively examine their impacts on biodiversity. There are a vast range of possible adaptation and mitigation measures for flood and coastal management, some of which are complementary to the conservation of biodiversity and thus represent win-win situations (Paterson et al., 2008). Among these are coastal accommodation and managed realignment (Table 6.2). Of greater concern are those, such as large dams, which impact negatively on biodiversity and its ability to adapt to climate change, while many coastal protection schemes will prevent habitats from moving inland, thus resulting in coastal squeeze.

There is also a lack of information on the potential impacts of many of the identified measures on biodiversity and this partly reflects a failure to identify such cross-sectoral impacts. While many of them are probably localised and/or negligible, those which could have a greater impact, such as some of the river channel measures, should be the subject of further research. There is a need to interpret the impacts in a landscape sense to understand the most appropriate scale of response to these challenges – these results suggest that there would be benefits if management addressed changes at broad scales, e.g. whole catchments, coastal cells and beyond.

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7. Tourism and Leisure

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This chapter examines the role of mitigation and adaptation in the tourism and recreation sector and its impact on European biodiversity. Information on adaptation and mitigation in the tourism and leisure industries is slowly beginning to trickle through the academic literature (compare, for example, agriculture, which has a comparatively long history of addressing these issues) (Bigano et al., 2006) and so far the focus (in Europe) has mainly been on activities based either in mountains or on beaches.

Tourism throughout Europe has grown considerably over the last 50 years and in many countries has become a hugely important economic force, both locally and nationally - representing nearly 4% of the combined GDP of all European countries (EEA, 2008). Increasingly also, tourists are more likely to access natural or semi-natural landscapes (mountains, downs, forests, lakes) or engage in ecotourism (Burger, 2000); this brings increased pressures to the biodiversity of Europe.

Additionally, tourism is one of the main factors behind an increase in demand for transport; in 2005, 59% of tourists travelled by car and 34% by air (EEA, 2008), two of the worst forms of transport for the environment. The advent of low-cost no frills air travel has further enabled quick and easy access to many parts of Europe as well as a rise in weekend and short breaks (they accounted for 35% of all European airline travel in 2007). This has also seen the emergence of many central and eastern European countries as destinations for holiday makers (European Travel Commission, 2008).

A number of sources have provide the backbone for this analysis but four, in particular, stand out: Simpson et al (2008) provide a very thorough overview of the adaptation and mitigation in tourism which complements another UNEP (and World Tourism Organization) publication (2008); Scott and McBoyle (2007), for their analysis of adaptation in the ski industry (which also provides the basis of the structure for the review on the effects on biodiversity); and, Gössling (2002) who reviews the environmental consequences of tourism.

The aim of this report is to provide an overview of technically feasible mitigation and adaptation measures for tourism and leisure activities in Europe and to assess their impact on European biodiversity. A brief introduction to the predicted effects that climate change will have on European tourism and leisure is included, as well as summaries of the main adaptation and mitigation issues. The focus of the report is mainly on 'outdoor' activities like skiing, hiking, hunting and boating as well as beach holidays because they based in environments that harbour higher levels of biodiversity - for this reason urban tourism is not included in the analysis. Biodiversity impacts are inferred from existing studies on the effects of the given activity on local or regional

7.1 The effects of climate change on tourism and leisure

Climate is one of the most important criteria for locating tourism centres and has a considerable effect on the choices of tourist destinations (Martin, 2005). Traditionally, tourists seeking sunshine have sought out areas in the Mediterranean zones; likewise, snow-sports are restricted to mountain areas. However, the predicted changes to European climate will undoubtedly affect these tourist destinations (Beniston, 2003; Hamilton et al., 2005; Agnew and Palutikof, 2006; Amelung and Viner, 2006; Hamilton and Tol, 2007; UNWTO, 2008). A summary of the likely effects that will impact tourism the most are:

- Mediterranean regions will become hotter and drier.
- Low lying coastal areas will suffer from increased winter storm damage and sea-level rise which may result in land loss.
- In mountainous regions there will be lower snow falls and warmer winter temperatures.

7.2 Adaptation in tourism and leisure

These changes will dramatically affect tourism throughout Europe and already we are seeing adaptation strategies installed to cope (e.g., greater use of snow making in ski resorts). Some tourism areas are very sensitive to climate change (sun, sea, sand and winter sports - (Bigano et al., 2006)) and will have to adapt, if possible, to maintain tourist numbers; however, even less sensitive areas will probably be affected by climate change too. The range of adaptation measures is broad and clearly will have to encompass different types of tourism and different locations. General patterns will emerge though:

- Gradual shift in tourism towards northern Europe and to mountain areas (Alps, Pyrenees, Caucasian, Fjällen).
- Scandinavia and other northern European countries will increase their summer and winter tourism.
- The mountainous regions will increase in summer visitors as tourists seek alternatives to hotter regions.
- Mediterranean regions will become hotter and drier and receive fewer tourists in summer but possibly more in spring and autumn.
- Low lying coastal resorts may construct barriers to contain sea-level rise or move tourism infrastructure further away from the coast.
- Sun and beach lovers from Western Europe will travel shorter distances reducing international tourist numbers.
- Residents of warmer southern European countries are less likely to holiday in their own countries and will travel abroad.
- In mountainous regions lower snow falls and warmer winter temperatures will result in a decline in snow-based activities as the

snow line increases in altitude; low-altitude resorts will particularly suffer - increases snow-making will be a short-term measure, but increasingly resorts will try to market other activities to replace skiing and boarding and extend their summer activities too (e.g., hiking).
- Promotion and development of other types of tourism such as ecotourism, cultural tourism.

7.3 Mitigation in tourism and leisure

Parts of the tourism industry (and tourist themselves) are attempting to mitigate climate change through various measures. Many tourism companies offer low-impact holidays involving carbon offsetting and environmentally-friendly resort features (e.g., renewable energy, local produce) and and in recent years tourists have used rail travel more (European Travel Commission, 2008). However, there is still much that can be achieved, particularly when the numbers of low-cost air flights continues to rise and new flight destinations are added to their list of places to visit

Simpson et al (2008) highlight four main challenges for the tourism industry to achieve mitigation of greenhouse gases and become carbon neutral:
- Elimination of greenhouse gas emissions by avoiding activities that are readily substitutable for less damaging activities and do not reduce the quality of the tourism experience.
- Reduction of greenhouse gas emissions by using energy efficient practices.
- Substitution of practices that emit large amounts of greenhouse gases with those that have lower emissions.
- Adoption of offset schemes to neutralise their carbon emissions.

Clearly these objectives can be aimed at sectors throughout the tourism industry from the most important in terms of emissions (transportation) through to others like accommodation and infrastructure construction. In this report we focus on each aspect of tourism separately: it is broken down into sections based on the supply side of tourism and leisure (i.e, tourism companies, hotels, golf courses etc.), the demand side (tourists, hunters and other people involved in recreation) and also the role of governments.

The following section is broken down into measures that are options for the supply-side (tourism industry), demand-side (tourists) or governments; the form of mitigation and/or adaptation is described which is then followed by its known or likely (inferred from related studies) impact on biodiversity.

7.4 Supply-side tourism: impacts on biodiversity

This section focuses on all aspects of adaptation and mitigation that tourism, leisure and travel companies (from travel agents to resort owners) are capable of implementing.

7.4.1 Golf courses

7.4.1.1 Increase irrigation

Mitigation measure: Not applicable.
Adaptation measure: Increased irrigation will be required to maintain greens in hotter and drier conditions.
Impact on biodiversity: Mixed - Will depend upon source of water. Additional demands for water will compete with agricultural demands. Extraction from water courses may have detrimental effects on river biodiversity. The creation of new reservoirs to supply water could be good (new habitat for birds, fish, insects) or bad (destruction of semi-natural habitat to create reservoir) - see also chapter 4 (Energy) for the impacts of reservoirs.

7.4.1.2 Location

Mitigation measure: Not applicable.
Adaptation measure: More golf courses may start to appear in northern Europe to cater for increased demand as holiday golfers reject golf courses in southern Europe.
Impact on biodiversity: Mixed - will depend on previous land-use type before conversion. Conversion from low biodiversity farmland may increase biodiversity (golf courses generally have higher levels of biodiversity than farmland - (Tanner and Gange, 2005)).

7.4.1.3 Extend golf season in northern Europe

Mitigation measure: Not applicable.
Adaptation measure: Milder weather in autumn, winter and spring may extend the gold season for the majority of 'fair-weather' golfers (Scott and Jones, 2006).
Impact on biodiversity: Minor - possible increase in golfers in spring may result in increased disturbance for nesting birds.

7.4.2 Seaside resorts

Climate change is likely to result in loss of beach or inland migration of beaches in some resorts, as well as increased flooding and coastal erosion; increased incidence of storms in winter will also damage coastal infrastructure. Furthermore, hotter and drier summers will result in increased droughts, desertification and an increase in heat stress and human discomfort. Mediterranean tourism attracts about 120 million tourist a year, most of which is to coastal areas (Kundzewicz et al., 2008).

7.4.2.1 Coastal engineering

Mitigation measure: Not applicable.
Adaptation measure: Whilst much of Europe's coastline is considered relatively robust to sea-level changes, some areas will be more vulnerable (coastal plains, deltas) (Stone and Orford, 2004). Coastal defences (sea walls, breakwaters) can be constructed to prevent coastal erosion and flooding.
Impact on biodiversity: The effects on biodiversity are complex and vary considerable from positive to negative and will depend on on local conditions - further details are found in the Chapter 6.

7.4.2.2 Move resort infrastructure away from sea

Mitigation measure: Not applicable.
Adaptation measure: If sea-level rise increases flood damage and coastal resorts may have to migrate away from the sea.
Impact on biodiversity: Neutral to negative - some new development is likely to impact on coastal habitats resulting in loss of biodiversity.

7.4.3 Freshwater resorts

Mitigation measure: Not applicable.
Adaptation measure: Hot and dry summers may result in more tourists seeking out inland water resorts to participate in water sports such as boating, swimming, water skiing, etc. Impact on biodiversity: Negative - increased use of inland waters like rivers, lakes is likely to increase disturbance of aquatic biodiversity. Also, if shoreline development is increased to cope with additional tourism, the effects on the littoral zone biodiversity would be threatened (Brauns et al., 2007).

7.4.4 Forest resorts and parks

Forests and woodlands play an important role in recreation and tourism in many European countries (Bostedt and Mattsson, 1995; Kuvan, 2005; Hill and Courtney, 2006) and increasingly recreation management is becoming important for forest managers alongside silviculture and conservation (Lacaze, 2000). For forests in hotter regions it is possible that recreation will become even more important as people seek woodland cover to escape the predicted hotter summers.

7.4.4.1 Forest management

Mitigation measure: Maintaining forest cover and restocking after felling is important to ensure carbon stocks in forested land are maintained.
Adaptation measure: There is increasing evidence that people using forests for recreation in hot, summer conditions prefer continuous canopy cover because of the shade it provides (Weinstein and Schiller, 1982; Schiller, 2001). If recreation is - or becomes - more important than silviculture and conservation, forest management may have to change to accommodate woodland visitors'

preferences.
Impact on biodiversity: Positive or negative - a change in management that enforces continuous canopy cover may have positive effects (many forest species require canopy shade) or negative (traditional coppice rotations in some woodlands have an adapted ecology that depends upon the cycle of light and gradual shade). Further, any change in management to encourage people raises the fire risk, increase litter, disturbance of wildlife and habitat damage resulting form trails, kiosks and other infrastructure (Weaver and Dale, 1978; Lacaze, 2000; Symmonds et al., 2000; Li et al., 2005; Thiel et al., 2007).

7.4.4.2 Development of forest resorts

Most countries have resort-based holidays in larger areas of forest (e.g., Centre Parcs in the UK, http://www.centerparcs.co.uk/index.jsp); if these resorts gain in popularity due to climate change it is likely that more will be developed.
Mitigation measure: Not applicable.
Adaptation measure: Increase usage in hot summers?
Impact on biodiversity: Neutral to negative - Forest resorts in plantation forests are unlikely to have a major detrimental impact on biodiversity; however, conversion of semi-natural forest will result in increased pollution, disturbance to wildlife, fire-risk, land-use change (chalets, restaurants, car parking, roads, trails, (Lacaze, 2000; Kuvan, 2005).

7.4.5 Ski resorts

Winter tourism and the ski industry are economically very important for alpine regions all over Europe, but are very vulnerable to warm winter seasons and future climate change because of their dependency on good snow conditions. The predicted increase in temperature will have severe impact on the available snow amount and snow reliability of alpine resorts (Alcamo et al., 2007). Milder winters have already been affecting resorts because of deficient snow (Koenig and Abegg, 1997).

The ski tourism industry is now very focused on adaptation but they will increasingly have to initiate the implementation of mitigation strategies too (Elsasser and Burki, 2002). Most resorts have yet to tackle mitigation efforts seriously though some are making headway (Lech in Austria, for example, has invested in a biomass communal heating plant which provides heat and hot water for 100 hotels, 200 homes and businesses by burning communal waste). Most mitigation measures in ski resorts will focus on four areas: heating, mobility, machines, and surrounding forest management and wood utilisation (Walz et al., 2008). Many of these measures are pertinent to other types of holiday resort too.

The literature on adaptation in the ski industry is slowly expanding (Koenig and Abegg, 1997; Elsasser and Burki, 2002; Scott and McBoyle, 2007; Scott et al., 2007; Hennessy et al., 2008; Scott et al., 2008); here we present the main adaptation strategies discussed to overcome future lack of snow.

7.4.5.1 Snowmaking

Snow making, as the most widespread climate adaptation, is widely used in ski resorts. It involves forcing water and pressurised air through a canon onto the slopes. A nucleating agent is sometimes added to the mix to ensure more water freezes and turns into snow. Snowmaking requires large amounts of water (either from groundwater, rivers, lakes or reservoirs) as well as an extensive plumbing system to move water around the resort to the canons.

Mitigation measure: Snowmaking is counter to any mitigation effort.

Adaptation measure: Climate change is predicted to reduce snow cover in mountainous regions, as more resorts suffer from lack of snow, more snowmaking facilities will be employed. It is however, at best a short-term response.

Impact on biodiversity: Very negative especially on vegetation. Rixen et al (2004; 2008; 2003) and Wipf et al (2005) have studied the effects of artificial snow cover on ski pistes and found that plant development was delayed and changes in vegetation types can occur due to increased water input and soil enrichment through snow additives. These additives could have a pathogenic effect on plants as they are derived from bacteria (Rixen et al., 2003). Moreover, snow production changes the local hydrology with possible negative impacts on aquatic species and the sensitive alpine ecosystems. To counter this, the additional layer of snow that snowmaking provides does help to protect plants and shrubs from grooming machines (Rixen et al., 2003). The creation of reservoirs to store water for artificial snow production is also likely to have a negative impact on biodiversity (Avakyan and Iakovleva, 1998).

7.4.5.2 Slope development

Resort expansion in climatically advantaged locations at higher altitude or on north facing slopes is often cited as a method to maintain incoming ski tourism. The development of facilities (ski lifts) higher up mountains would be required and easier access to nearby glaciers would be another strategy. This is already happening in some resorts (in the Austrian Tyrol, a ban on skiing in a protected area has been lifted to allow skiers access to the Gepatsch glacier (Schiermeier, 2004)).

Mitigation measure: Not applicable.

Adaptation measure: To combat poor snow cover in the lower parts of the resort.

Impact on biodiversity: Negative - this will have a severe impact by reducing the area of still untouched high elevation zones. It is not just vegetation (Fahey, 1998; Wipf et al., 2005) that will be affected, but also the already threatened alpine wildlife through disturbance (Laiolo and Rolando, 2005; Rolando et al., 2007; Zohmann and Woss, 2008) as mountain tops provide the last vestige of habitat for many threatened species (Arlettaz et al., 2007). Grooming will lead to mechanical damage of woody vegetation and compaction of the snow cover decreasing its insulation capacity and so increasing the frost risk for the plants.

7.4.5.3 Cloud seeding

This weather modification technology has been used in America and Australia to encourage precipitation (Scott and McBoyle, 2007). Because of its high cost and questionable efficiency, this method is not likely to be extensively used though.

Mitigation measure: Cloud seeding is counter to any mitigation effort.

Adaptation measure: To increase snow fall.

Impact on biodiversity: Negative - Cloud seeding involves the use of silver iodide crystals as founder nuclei for cloud development; this may have a detrimental effect - in the US silver concentrations in bryophytes in known cloud-seeding areas have been associated with increased levels of chronic wasting disease in wild mammals (Purdey, 2004).

7.4.5.4 Glacier insulation

Mitigation measure: Not applicable.

Adaptation measure: The Andermatt resort in Switzerland have used a large (4,000 m2) blanket to reduce summer melting on glaciers to maintain access to the glacier for skiers in the winter.

Impact on biodiversity: No known effects.

7.4.5.5 Indoor skiing

Scott and McBoyle (2007) suggest that the further development of indoor ski slopes may be a useful adaptation strategy to encourage early ski interest in potential skiers from urban areas.

Mitigation measure: Indoor ski slopes require large amounts of energy to maintain the cold conditions for skiing - this option is counter to any mitigation effort.

Adaptation measure: If outdoor slopes are threatened by lower snow fall then keen and future skiers may switch their interest to indoor slopes.

Impact on biodiversity: Neutral to negative - the development of large buildings to house indoor slopes may require conversion of land which harbours biodiversity.

7.4.5.6 Diversification

Mitigation measure: Non-use of ski-lifts and cable cars will save energy usage.

Adaptation measure: Activities diversification is another solution to deal with the lack of snow. Several resorts are already developing alternative activities for the non-skiing tourist (snow-shoeing and hiking, paragliding, health and spa facilities, local cuisine - eating and cookery courses, ice-climbing), as well as transforming themselves into four-season resorts offering non-winter activities (e..g, hiking, mountain biking).

Impact on biodiversity: Positive to negative - if diversification is promoted at the expense of seeking higher ski slopes and snow-making then the likely impact will be good; however, the impact on biodiversity will depend on the type of activities developed. If they result in new infrastructure and higher tourist numbers in summer it will probably increase disturbance to alpine wildlife (Zohmann and Woss, 2008).

7.4.5.7 Renewable energy sources

Mitigation measure: For heating, electricity generation and transport. Options include wood for domestic or central heated systems, hydropower, geothermal, solar and wind power.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive to negative. The further development of hydropower renewable energy can have major environmental implications for a range of habitats and species (see Energy chapter for more detail). Solar, wind and geothermal are less harmful (although if badly designed and implemented, can be). The conversion of timber for woodfuel is potentially good for biodiversity if it maintains sustainable woodland management regimes in local forests (Decocq et al., 2004; Sergio and Pedrini, 2007).

7.4.5.8 Increase energy efficiency

Mitigation measure: Improve efficiency of vehicles, machines, and boilers as well as increase building insulation.
Adaptation measure: Not applicable.
Impact on biodiversity: Neutral to positive - the French resort Verbier uses a sonar detector on their piste grooming machines to measure snow depth (so avoiding the need for artificial snow on deep pistes which will save water and energy) but it will also allow the groomers to avoid areas where snow cover is too thin (and hence avoid damaging vegetation).

7.4.5.9 Forest management

Mitigation measure: Increase forest cover in and around a resort to offset the resort's energy usage.
Adaptation measure: Additional tree cover may provide protection against avalanches (Höller, 2007) and rock slides brought about by warmer conditions (Martin et al., 2001; Höller, 2007).
Impact on biodiversity: Negative to positive - afforestation on species-rich grassland should be avoided (Buscardo et al., 2008), otherwise planting trees (especially native species) will be good for biodiversity (Van Der Horst and Gimona, 2005).

7.4.5.10 Resort conglomerates

Many ski resorts are owned by large conglomerates (e.g., Compagnie des Alpes which owns over 16 resorts in France). The multi-corporation ownership of many resorts allows the company to reduce resorts economic sensitivity to climate variability with the fusion of small resorts or in acquiring ski areas in many different locations (Scott and McBoyle, 2007).
Mitigation measure: Large corporations are more likely to be able to afford conversion to renewable energy.
Adaptation measure: Gives the ability to spread the risk of climate change affects on ski resorts over a wide geographical range.
Impact on biodiversity: Positive to negative - good, if conglomerates can resist the urge to expand their low-lying resorts further up mountains because they already have other high mountain resorts; bad if they use their financial clout

to do the opposite.

7.4.6 Financial and insurance sector

As the impacts of climate change become more pronounced insurance companies may demand that tourist companies improve the ability of their buildings and other infrastructure to withstand climate change events.

7.4.6.1 Weather insurance

Mitigation measure: Not applicable.
Adaptation measure: Insurance companies may demand that tourism and recreation facilities have additional 'climate proofing' (e.g., from storms, floods, avalanches) to increase adaptive capacity (Mills, 2003; Crichton, 2007).
Impact on biodiversity: Neutral to negative - new or additional infrastructure may impact on nearby habitats (e.g., flood barriers on rivers - see Chapter 6).

7.4.7 Transport

The largest emitter of greenhouse gases in the tourism sector is travel to and from destinations which accounts for 75% of all tourism emissions (Hendriks, 2007); of this air travel accounts for the largest share (between 54% and 75% of the total), the next largest share is from car travel which accounts for 35% (Peeters et al., 2007). Most journeys are taken within the EU-25 (90% of trips) and by ground transport (80% of journeys); Train, coach and ferry account for 20% of tourism journeys, but have an almost insignificant environmental impact (Peeters et al., 2007).

7.4.7.1 Airlines

Mitigation measure: Replace ageing planes with new, more efficient models.
Adaptation measure: Not applicable.
Impact on biodiversity: Neutral.

7.4.7.2 Hire-car

Mitigation measure: Adopt higher efficiency car-hire pool. New car models are increasingly efficient (even large 5 seat cars with lean-burn diesel engines).
Adaptation measure: Fit air-conditioning to all cars in hot regions.
Impact on biodiversity: Neutral.

7.4.7.3 Railway

Mitigation measure: Increase rail travel - this could be achieved by improving network connections, installing more high-speed lines and offering cheaper tickets.
Adaptation measure: Air conditioning on carriages in hot regions. Extreme heat may damage railways.
Impact on biodiversity: Positive to negative - if rail travel takes a larger share of the tourism market at the expense of air and road travel (and assuming new lines are not created), air pollution will be reduced (and therefore the concomitant effects on species and habitats). Conversely, if new railway networks are created it is likely that they would result in significant habitat

loss.

7.4.7.4 Coaches

Mitigation measure: Coaches emit far less GHGs per person compared to cars or planes.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive - if increased coach usage results in reduced car and plane travel air pollution is likely to be reduced.

7.4.8 Tour operators

More tour operators realise that there is a market for tourists who wish to minimise their environmental impact and are now offering green or sustainable holidays which encompass sustainable travel (rail), carbon offsetting, hotels run on renewable energy and meals made with local produce. This is backed up by a plethora of green travel books available to the tourist as well as regular newspaper articles.

7.4.8.1 Off-setting

Travel companies are increasingly becoming allied with carbon offsetting schemes to allow the tourist to offset their holiday GHG emissions.
Mitigation measure: Offsets normally involve emissions-reducing or carbon sequestering projects; these can be in the form of renewable energy (e.g., wind farms, hydropower), energy efficiency projects, landfill methane mitigation or forestry projects.
Adaptation measure: Forestry projects in some circumstances may afford flood alleviation properties (Laurance, 2007) - see also Chapter 6.
Impact on biodiversity: Positive to negative - forestry offset schemes involving planting native trees are normally beneficial for biodiversity particularly if they are planted on degraded land. However, use of exotic and invasive species in some plantations has questionable benefits for biodiversity particularly if planted on existing species-rich habitats (e.g., grasslands) (Schulze et al., 2002; Caparros and Jacquemont, 2003; Jackson et al., 2005; García-Quijano et al., 2007). Offset schemes using hydropower or biofuels may also result in a reduction of biodiversity.

7.4.8.2 Hotels and restaurants

Mitigation measure: Use of renewable energy for heat and electricity; better insulation for buildings in cold areas; no air conditioning; food (or organic) sourced locally has a lower carbon footprint.
Adaptation measure: Not applicable.
Impact on biodiversity: Mostly neutral to positive - some forms of renewable energy may harm biodiversity in their construction and use (e.g., hydropower - (Poff et al., 2007)) but generally all these mitigation methods will have no effect on biodiversity; organic food production has been shown to have higher levels of biodiversity on the farms (Bengtsson et al., 2005; Fuller et al., 2005) - see also Chapter 2.

7.5 Demand-side: impacts on biodiversity

This section concerns the individual choices that tourists or pleasure seekers make in order to help mitigate climate change. Awareness of climate change issues is becoming very large now and more and more people wish to travel and holiday as sustainably as possibly. All travel aspects are dealt with in a separate sub-section.

7.5.1 Hunting

Mitigation measure: Not applicable.
Adaptation measure: Climate change may lead to growth of deer populations in northern Europe (due to milder winters and a longer growing season) - this may increase deer hunting throughout the region.
Impact on biodiversity: Positive - over-grazing by growing deer populations have resulted changes in ground-flora structure and diversity in many woodlands throughout Europe (Kirby, 2001; Morecroft et al., 2001; Whigham, 2004; Corney et al., 2008); an increase in hunting is likely have positive effect in controlling deer numbers.

7.5.2 Skiing

Keen skiers can do much to reduce their impact on the environment and although the industry generally has a poor environmental record, there are options available to skiers with a conscience (travel options are dealt with in section 3.2.6). Adapting to poor snow is possibly of more concern to most skiers though.

7.5.2.1 Alter timing of skiing during season

Mitigation measure: Not applicable.
Adaptation measure: Last minute bookings or choosing times of the year when snow is most likely to be good.
Impact on biodiversity: Negative - if all skiers target the good snow weeks the higher density of skiers will have a negative impact on local biodiversity.

7.5.2.2 Alter skiing location

Mitigation measure: Not applicable.
Adaptation measure: Skiers will choose to avoid low-lying resorts that do not receive enough snow and focus on higher altitude resorts that are more snow-sure.
Impact on biodiversity: Positive and negative - as above, a greater density of skiers in high altitude resorts is likely to have a negative impact on local biodiversity (Wipf et al., 2005; Young et al., 2005; Rolando et al., 2007); conversely, if low lying resorts become quieter, biodiversity may benefit.

7.5.2.3 Substitute skiing with another recreation activity

For tourists that enjoy being in the mountains in winter anyway, other sports may be suitable substitutes if their is insufficient snow for downhill skiing, for example, snow-shoeing, or hiking.

Mitigation measure: Reduced use of ski lifts.
Adaptation measure: Winter tourists can adapt to lack of snow for skiing by replacing skis with hiking boots or snow shoes (where there is snow).
Impact on biodiversity: Positive - any reduction in downhill skiing is likely to be good for biodiversity - hikers will not be concentrated as much on slopes and are therefore less likely to affect biodiversity.

7.5.2.4 Alter length of stay

Mitigation measure: Visiting resorts for one or two week stays is a far better option than going on many short, weekend breaks - CO2 emissions from travelling will be lower.
Adaptation measure: Not applicable.
Impact on biodiversity: Neutral.

7.5.2.5 Change style of skiing

Ski mountaineering and ski touring (where skiers use special bindings and 'skins' attached their skis to provide grip whilst going uphill) enables skiers to access backcountry areas without the need of any motorised carriage to access high mountain tops.
Mitigation measure: All travel on snow is achieved by human power hence no need for energy intensive ski lifts etc.
Adaptation measure: Skiers are not bound by the area limits of a ski resort (given that access to backcountry areas is granted), they can ski anywhere there is snow (assuming it is safe).
Impact on biodiversity: Ski mountaineering is unlikely to convert many normal skiers from using lifts (it requires high levels of fitness and as well as mountaineering skills) but it is almost wholly without negative impact on biodiversity.

7.5.2.6 Web or conservation group information

A number of websites concerning the environmental impacts of ski resorts exist, perhaps the most complete is 'Save Our Snow' (http://www.saveoursnow.com/index.htm) which along with rating resorts, offers green travel information and highlights new green schemes at resorts; others including the Ski Club of Great Britain 'Respect the Mountain' campaign (http://www.skiclub.co.uk/skiclub/respectthemountain/environment/default.asp) as well as a French site (http://www.mountain-riders.org/) and some American sites (e.g., http://www.keepwintercool.org/index.html). These websites allow the user to identify the greenest resorts which are rated under a number of criteria including: climate policy, building policy, cleaner fuel, sewage reduction, traffic reduction measures, waste recycling, working for ISO14001, obtained ISO14001, heat recycling, 100% renewable power user, renewable power generator and rail access.
Mitigation measure: Allows the skier to choose the most environmental resort based on the above criteria.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive - if access to information allowing the skier to

choose their destination based on environmental criteria results in greater percentage of skiers choosing these resorts other resorts are likely to follow their lead and adopt higher environmental standards. Whilst some environmental measures may result in biodiversity loss (e.g., a hydropower scheme) most should be beneficial or neutral.

7.5.3 Beach Tourists

7.5.3.1 Alter destination away from Mediterranean resorts to northern European resorts

Mitigation measure: Not applicable.
Adaptation measure: Mediterranean resorts may be too hot and dry in the summer, sun lovers may decide to travel to northern European beach resorts.
Impact on biodiversity: Neutral to negative - if beach tourism migrates north to relatively quiet resorts it may bring about more development which could have major consequences for local biodiversity (Vaughan, 2000; Davenport and Davenport, 2006).

7.5.4 Eco-tourists

Ecotourism is frequently cited as a method of benefiting conservation projects throughout the world (and Europe) (Gossling, 1999; Burger, 2000). It involves tourists paying to see some form of natural wonder or even participate in conservation work (Cousins, 2007) - usually in beautiful areas or with large charismatic fauna (e.g., sea-turtles).

7.5.4.1 Location

Mitigation measure: Assuming eco-tourists care equally about climate change as they do about conservation, it would be reasonable to assume that they will forego long-distance air travel to conservation sites for ones nearer to home.
Adaptation measure: Eco-tourists may prefer to travel to colder or more northerly locations instead of southern European sites if they become too hot due to climate change.
Impact on biodiversity: Positive or negative - the two biodiversity hotspot areas in Europe are the Mediterranean zone and the Caucasus mountains - if ecotourism trips to these places decline (from rich, northern Europeans) they may suffer a reduction in vital funding for conservation efforts. Conversely, if eco-tourist travel nearer to home or to cooler, northern European locations, these sites are likely to see raised income which will benefit local biodiversity.

7.5.4.2 Transport choices

The relative mitigation potential of choice of travel has mostly been dealt with in section 3.1.8; however choice of travel mode will make a huge impact for mitigation with rail and coach the best methods. In terms of biodiversity impact, if more people use rail travel (and governments invest in better networks), the threat of adding new runways for major air hubs may be mitigated (e.g., the third runway at Heathrow). Other travel options are not likely to make any difference for biodiversity although rail is probably marginally better than road travel. In order of preference for minimising environmental impact (GHG emissions, accidents, nature & landscape, air quality and noise), rail travel is the best option, closely followed by coach travel with car and air travel significantly the worst (Peeters et al., 2007).

7.5.4.3 Offsetting

Tourists and travelers can personally offset their GHG emissions using carbon offset companies.
See section 7.4.8.1 for more detail.

7.5.5 Governance

Governments (whether EU, national or regional) play an important role in the tourism industry in many ways (e.g., development of infrastructure, laws and legislation for tourism facilities standards, economic incentives, promotion - although increasingly European governments are cutting funding to to the tourism industry (European Travel Commission, 2008)). At the European level (Commission of the European Communities, 2006), the EU's objective is to :

- "Promote the competitiveness and sustainability of European tourism
- Improve the regulatory environment for tourism
- Enhance the understanding and visibility of tourism, and
- Support the promotion of European destinations".
-

Governments also have a role in combating climate change and how it affects tourism (e.g.,):

- Mitigation
  - Promotion and incentives for energy efficiency
  - Taxation of inefficient energy use
  - Reduction in high GHG energy providers and investment in renewables.
- Adaptation
  - Flood alleviation and mitigation
  - Coastal realignment
- Awareness
  - Education
  - Investment in research.

7.5.5.1 Investment in green infrastructure

Mitigation measure: Renewal or creation of railways, trams or bus services. Renewable energy schemes.
Adaptation measure: Flood and sea-level rise defence installation, installation of desalination plants - see also Chapter's 4 and 6.
Impact on biodiversity: Positive to negative - transport initiatives results in reduced car and plane travel, air pollution is likely to be reduced. Any large

infrastructure development is likely to impact on local habitats although some development may have minimal impacts and may even involve habitat creation. Desalination plants can be very damaging to local biodiversity and include problems like marine pollution, change in land-use, changes in groundwater and noise pollution (Einav et al., 2003; Sadhwani et al., 2005; Lattemann and Hopner, 2008).

7.5.5.2 Improved weather forecasting

Mitigation measure: Not applicable.
Adaptation measure: Improve risk assessment and resort business decision making if weather forecasting improved seasonal forecast abilities (Scott and McBoyle, 2007) (applied for ski resorts but applicable to any tourist area).
Impact on biodiversity: Neutral to negative - if the accuracy of seasonal forecasts increased skiers would book only in weeks with good snow forecasts resulting in large densities of skiers in those weeks and greater disturbance of alpine wildlife. Likewise, tourist numbers to national parks and other conservation areas would peak in good weather increasing path erosion, wildlife disturbance, pollution, etc.

7.5.5.3 Taxation on high GHG transport

Mitigation measure: In February 2007 the UK government introduced an increase in the Air Passenger Duty ostensibly as a climate change tax.
Adaptation measure: Not applicable.
Impact on biodiversity: Neutral - there is little evidence that carbon taxes have so far reduced air travel although the total cost of many air journeys is still comparatively low. An increase in taxation on air (or car fuel) would reduce travel.

7.5.5.4 Subsidies for green travel

Mitigation measure: Government subsidy of rail or coach travel.
Adaptation measure: Not applicable.
Impact on biodiversity: Positive - if it reduces the numbers of tourists using car or air travel (lower pollution, less road and airport development).

7.6 Conclusion

Like most of the other sectors in this report, the mitigation and adaptation measures in the leisure and tourism industry will range from positive to negative effects on biodiversity but will depend greatly on local environments. The largest mitigation potential is through adopting greener travel which will require efforts from the airline and car industries, governments and the individual. The advent of the green holiday is already here and it is possible to travel to a destination, stay in accommodation and enjoy the holiday activities without emitting too much GHGs. By offsetting emissions with a carbon trading company too the individual (or travel company) can neutralise their total GHG emissions for their trip. Furthermore, it is possible to do all this and not negatively impact on biodiversity - most travel companies promoting green holidays promote all aspects of the environmental agenda and indeed many ecotourism companies will benefit biodiversity through tourist participation (although there have been exceptions in other parts of world).

However, climate change adaptation in the tourism industry will be harder too accommodate without affecting biodiversity. The two types of tourism that will be mostly badly affected will be beach holidays and skiing (which already is); for both, the outlook is not bright and efforts to ameliorate the effects of climate change will either be costly or impossible and more than likely will be harmful to biodiversity. The ski industry faces a difficult challenge and many resorts may not be able to offer downhill skiing in a few decades; beach resorts have greater potential to adapt - new sea-level rise defences and desalination plants can be installed (although they may do considerable damage to marine and coastal biodiversity) - and sun-seekers will be able to avoid the hot months in favour of spring and autumn holidays.

7.6.1 Synergies

There are too few opportunities for synergies among mitigation, adaptation and biodiversity (win-win-wins – see figure 1); perhaps the best examples though revolve around forests. Forest management throughout Europe is increasingly accommodating mitigation principles (maintaining good carbon stocks in the forest) as well as ensuring that forests are enjoyable environments for visitors (and even centres for tourists) . European summers are predicted to become hotter which suggests that more tourist and leisure seekers will look to forests for their shade and cooler environment. Forest managers who maintain a continuous canopy cover (with a possible need for new species to adapt to a warmer climate) for visitors will reduce their harvesting impact on the forest which should benefit biodiversity (although it will also require sensitive management of visitors). Likewise, ski resorts that plant woodland groves for mitigation and adaptation (avalanche protection) will benefit biodiversity be creating new habitats.

7.6.2 Future research needs

It is apparent from this review that some parts of the tourism industry have been reasonably well covered in the mitigation and adaptation literature (e.g., skiing), others less so (e.g., ecotourism); Simpson et al (Simpson et al., 2008) have bemoaned the gaps in the published literature, but the gap is even larger when one examines the lack of research on the impacts of these measures on biodiversity. This problem is partly surmountable, for much of the review here, impacts have been inferred from pertinent ecology, environmental and conservation literature; however, there is still a need for more, original and relevant research in this area.

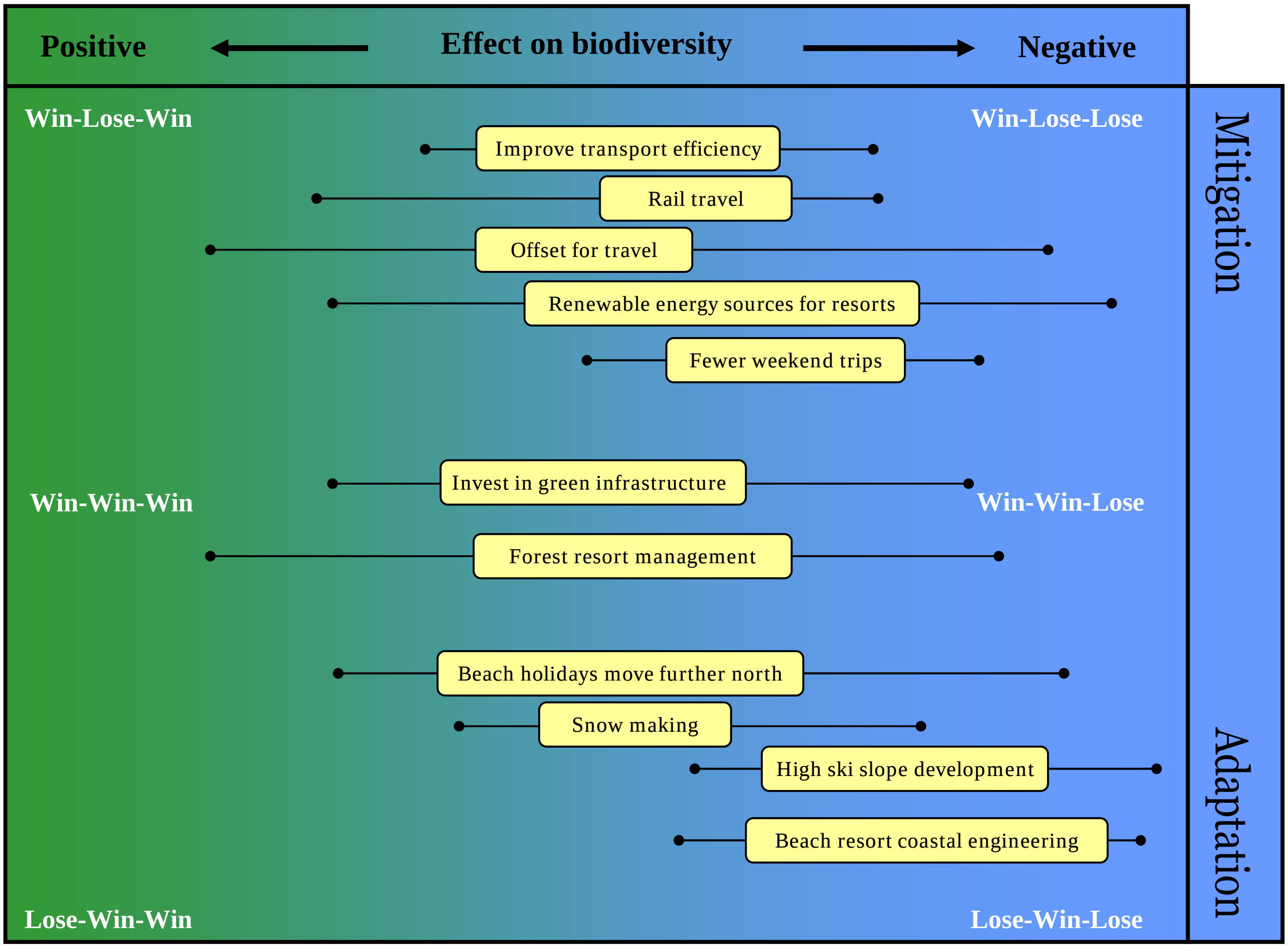

Figure 1: Known and potential relationships between mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on a literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts.

Bigano et al (Bigano et al., 2006) have highlighted the need for more research concerning tourist behaviour (page 179):

1. "Whether summer tourists would shift their holidays in time (to spring or autumn) rather than in space (up mountain or poleward);
2. the relative importance of winter holidays and summer holidays in mountainous areas;
3. the relative importance of climate and climate-sensitive determinants of holiday destination choice, such as temperature, precipitation, humidity, weather stability, air and water quality,

vegetation, and landscape;

4. the connection between climate and coast – for example, will central France become more popular or will people switch from the Costa Brava to the Baltic Riviera directly?;
5. the effect of climate on business trips and visits to friends and relatives – are such trips made without any consideration of climate? Or could it be friends and family visits, take place more often when the friends and family live in climatically more attractive places? Conference tourism may also not be completely independent of climate; and,
6. the effect of climate on decisions on the location of holiday homes and retirement location; and,
7. whether the relationships between climate and tourist destination choice are constant over time.

There is a gap in another area which needs examining too: the effects that climate change will have on disease (human, animal and plant pathogens) and the knock-on effects that it can have on tourism (and biodiversity). One example is the possible increase in ticks in the countryside under milder winters and warmer summers (Lindgren and Gustafson, 2001) - will this reduce visits to woodlands, hills, etc (and would this be good for biodiversity?)? Furthermore, one only has to review the effects that foot-and-mouth disease had on the British tourist (and agriculture) industry in 2001 (Sutherland, 2004) to question whether there are other pathogens that may become more prevalent under future climate change.

7.6.3 Table of impacts

The table below summarises the impact of each measure on biodiversity. It identifies the worst-case management scenario (e.g., a careless and inconsiderate adoption of a measure) and the best-case (e.g., following Good Practice); it also identifies the habitats and taxa affected. The arrows indicate the degree of impact:

↑ Highly beneficial for biodiversity,
↗ Moderately beneficial for biodiversity,
⇔ No known effect on biodiversity,
↘ Moderately detrimental for biodiversity,
↓ Highly detrimental for biodiversity,
? Indicates uncertainty over outcome due to lack of reliable data

Mitigation or Adaptation Strategy	Biodiversity Impact		Habitats affected									Taxa affected					
	Impact under worst practice	Impact under best practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland and othded areas	Unvegetated or sparsely vegetated habitats	Agricultural, horticultural and domestic habitat	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants
Irrigation on golf course	↘	↗			●	●	●	●	●		●	●	●	●	●	●	●
New golf courses	↘	↗			●	●	●	●	●		●	●	●	●	●	●	●
Extend golf season	↘	↔			●	●	●	●	●		●	●	●	●	●	●	●
Coastal engineering	↔	↔		●								●		●	●	●	●
Move beach resort infrastructure	↔	↔		●			●	●		●	●	●		●		●	●
Forest management	↔	↔			●		●	●	●	●	●	●	●	●	●	●	●
Development of forest resort	↓	↗			●				●	●	●	●	●	●	●	●	●
Snowmaking	↓	↘			●		●								●		●
Slope development	↓	↘					●		●		●	●	●	●	●	●	●
Cloud seeding	↔	↔	●	●	●	●	●	●	●	●	●	●			●		●
Glacier insulation	↔	↔			●												
Indoor ski	↘	↔					●			●	●						●
Ski diversification	↘	↗	t				●	●	●	●	●	●	●				●
Renewable energy	↘	↗			●		●	●	●	●	●	●	●	●	●	●	●
Energy efficiency	↔	↗															
Forest management	↘	↗							●	●	●	●	●	●	●	●	●
Resort conglomerates	↘	↗			●		●	●	●	●	●	●	●	●	●	●	●

Weather insurance	↘	⇔															
Airlines	⇔	⇔			●		●	●	●	●	●	●	●	●	●	●	●
Hire-car	⇔	⇔															
Railway	↘	↗															
Coach travel	⇔	↗															
Offsetting	↓	↑			●		●	●	●	●	●	●	●	●	●	●	●
Hotels	⇔	↗															
Hunting	⇔	↗					●	●	●	●	●	●	●				●
Ski – change visit time	↘	⇔			●		●	●	●	●	●	●	●	●	●	●	●
Ski – change location	↘	↗					●	●	●	●	●	●	●	●	●	●	●
Ski substitute with other activity	⇔	↗			●		●	●	●	●	●	●	●	●	●	●	●
Alter length of stay	⇔	⇔															
Ski mountaineering	⇔	↗					●		●	●		●	●				●
Web information	⇔	↑															
Change beach destination	↘	⇔	●	●	●		●	●	●	●	●	●	●	●	●	●	●
Change in ecotoursim location	↓	↑	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Improve weather forecast	↘	⇔					●	●	●	●	●	●	●	●	●	●	●
Tax GHG	↘	↗					●	●	●	●	●	●	●	●	●	●	●
Invest green infrastructure	⇔	⇔					●	●	●	●	●	●	●	●	●	●	●
Subsidize green travel	↘	⇔					●	●	●	●	●	●	●	●	●	●	●
Subsidize resort energy	⇔	⇔															

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8. Human health

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8.1 Introduction

Emerging evidence suggests that climate change will have diverse implications for human health. The increasing incidence of extreme weather events such as heat waves, floods and storms may affect human health and well being directly. The 2003 heat wave which caused thousands of casualties across Europe (Vandentorren et al. 2006) represents one example for the vulnerability of human societies and the deficits of private and public infrastructure to encounter such extreme events. In addition, climate change may result in a series of indirect effects, for example changes in the distribution and seasonality of vector-borne, water-borne, and other infectious diseases, as well as allergenic pollen species (Haines et al. 2006, Confalonieri et al. 2007). The recent local outbreak of Chikungunya in Italy (Enserink 2007) demonstrates the ability of novel vectors and their associated pathogens to persist in certain European regions. Future scenarios built on rising temperatures and altered patterns of precipitation suggest an increased susceptibility of large areas across the temperate zone to the establishment of diverse vectors and pathogens (e.g. Brownstein 2005, Scholte and Schaffner 2007). Further impacts of climatic alterations may emerge from increased air pollution as caused by forest fires and ground-level ozone production (Watson et al. 2005).

In the face of multiple pressures caused by climatic alterations several adaptation measures have been considered to reduce the negative effects on human health. These measures include investments into public education programs, the establishment of early warning systems, vaccination programs and schemes for vector and pathogen control (Confalonieri et al. 2007, Zebisch et al. 2005). Despite the frequently acknowledged need to adapt to climate change, most of the proposed adaptation measures have not been implemented by national authorities and even in developed countries coordinated action is missing (Zebisch et al. 2005).

Measures to prevent heat related diseases and vector-borne diseases are currently in the focus of the scientific literature. Therefore, the present review concentrates on adaptation strategies related to these two topics and their likely impacts on biodiversity. The following sections provide an overview on both, currently implemented adaptation measures and those which may become relevant in the future.

8.2 Measures of mitigation and adaptation and their impact on biodiversity

8.2.1 Heat waves

8.2.1.1 Education programs

Mitigation measure: Not applicable.
Adaptation measure: Reduce individual vulnerability to heat through altered behaviour.
Impact on biodiversity: No effect.

8.2.1.2 Early warning systems

Mitigation measure: Not applicable.
Adaptation measure: Reduces the incidence of heat stroke and heat mortality.
Impact on biodiversity: No effect.

8.2.1.3 Improvement of emergency plans

Mitigation measure: Not applicable.
Adaptation measure: Enhances the ability of medical emergency services and other health infrastructure to respond to particular natural hazards.
Impact on biodiversity: No effect.

8.2.1.4 Passive cooling of buildings through improved isolation and building design

Mitigation measure: Decreases energy use for active cooling and thereby green house gas (GHG) emissions. May also safe energy and reduce GHG emissions during the heating period.
Adaptation measure: Reduces the incidence of heat stroke and heat mortality.
Impact on biodiversity: Birds, mammals and invertebrates living in urban habitats may loose their breeding sites if these measures are not conducted appropriately, in particular with regard to façade refurbishment of old buildings.

8.2.1.5 Active cooling of buildings

Mitigation measure: Not applicable.
Adaptation measure: Reduces the incidence of heat stroke and heat mortality, particularly in nursing homes and hospitals.
Impact on biodiversity: Increases energy use and GHG emissions (depending on energy source) and is therefore expected to affect several habitats and taxa indirectly.

8.2.1.6 Afforestation and increasing the coverage of open space vegetation to reduce urban heat islands

Mitigation measure: Reducing urban heat islands by increasing the coverage of open space vegetation and afforestation may lower indoor temperatures thereby. These measures may lead to a reduced energy use for air conditioning and thus may contribute to reduce GHG emissions.

Adaptation measure: This measure is considered to reduce indoor and outdoor temperatures (New York City Regional Heat Island Initiative 2006) thereby reducing heat stroke and heat mortality among humans. Further, afforestation within urban areas may improve air quality as it reduces ozone formation and accumulation (Taha 2008 and references)
Impact on biodiversity: Additional green corridors within urban areas are known to provide habitat for a number of taxa, thereby increasing urban biodiversity (Cornelis and Hermy 2004).

8.2.1.7 Surface modifications to reduce urban heat islands

Mitigation measure: The use of light surface materials reduces the heat islands effect and thus, likely GHG emissions caused by air conditioning.
Adaptation measure: Increasing albedo by using light surface materials leads to lower indoor and outdoor temperatures (New York City Regional Heat Island Initiative 2006) and reduces ozone formation and accumulation (Taha 2008 and references)
Impact on biodiversity: Not known.

8.2.2 Vector borne diseases

8.2.2.1 Education programs

Mitigation measure: Not applicable.
Adaptation measure: Reduces individual vulnerability. For example, altered human behaviour may lead to reduced exposure to vectors and therefore, may decrease transmission rates (Hayes and Gubler 2006).
Impact on biodiversity: No effect.

8.2.2.2 Use of insect repellents

Mitigation measure: Not applicable.
Adaptation measure: Wearing insect repellents on clothes and skin may reduce exposure to vector species (Hayes and Gubler 2006).
Impact on biodiversity: No effect.

8.2.2.3 Early warning systems

Mitigation measure: Not applicable.
Adaptation measure: Early warning systems may improve individual adaptation measures to encounter insect outbreaks.
Impact on biodiversity: No effect.

8.2.2.4 Vaccination programs

Mitigation measure: Not applicable.
Adaptation measure: Vaccination may provide resistance of a human population against pathogens.
Impact on biodiversity: No direct effect. Biodiversity may benefit from vaccination if vector control by pesticides can be reduced.

8.2.2.5 Draining wetlands

Mitigation measure: Not applicable.
Adaptation measure: Draining wetlands destroys the breeding habitat of mosquito species. This measure was a component of former malaria control programs but is currently not applied in Europe.
Impact on biodiversity: Drainage has been shown to reduce biodiversity of wetlands (Coulson et al. 1990, Adamek and Sukop 1992). As wetlands usually inhabit a large number of species (Keiper et al. 2002, Zedler and Kercher 2005), a significant loss of biodiversity may result if wetlands are drained for mosquito control. Mediterranean wetlands may be particularly endangered as mosquito borne diseases may spread into these regions first.

8.2.2.6 Mosquito control by introducing fish

Mitigation measure: Not applicable.
Adaptation measure: *Gambusia affinis* mosquito fish and other fish species act as biological control agent against mosquito larvae (Chandra et al. 2008).
Impact on biodiversity: Introduced non-native species may compete with native species for resources, thereby altering community structures, food webs and affecting ecosystem functions (Sax et al. 2005). Introduced fish species have been shown to replace native fish species (Leonardos et al. 2008) or to alter environmental conditions within waterbodies adversely (Zambrano et al. 2001). Predation by *Gambusia affinis* which was introduced for mosquito control has been shown to adversely affect amphibian populations (Goodsell and Kats 1999), arthropod populations (Leyse et al. 2004) and to contribute to the extinction of populations (Gamradt and Kats 1996).

8.2.2.7 Mosquito control using Bacillus thuringiensis var. israelensis toxine (Bti)

Mitigation measure: Not applicable.
Adaptation measure: If digested Bti prevents the growth of mosquito larvae, thereby reducing mosquito populations.
Impact on biodiversity: Although considered as environmentally safe (Becker and Zgomba 2007) repeated Bti applications have been shown to affect aquatic non-target organisms (Boisvert and Boisvert 2000). Adverse effects on food webs in wetland habitats may result (Boisvert and Boisvert 2000). Other work demonstrated low impacts on non-target insect species (Charbonneau et al. 1994).

8.2.2.8 Mosquito control using insecticides

Mitigation measure: Not applicable.
Adaptation measure: Insecticides kill adult mosquitoes leading to a disruption of pathogen transmission.
Impact on biodiversity: The application of current pesticides within mosquito management schemes seem to impact aquatic biodiversity to a minor extent (Davis et al. 2007). However, more research should include more sensitive species into risk assessment (Davies et al. 2007). A number of countries in

Africa and Asia still use DDT for mosquito control. DDT represents one of the most efficient agents against malaria vectors. Currently, there is much controversial discussion on the international ban on its outdoor use (Ross et al. 2000, Ferriman 2001). DDT and its derivates accumulate in all tissues of living organisms and has been shown to be toxic to freshwater and marine microorganisms, fishes, amphibians and birds (WHO 1989, Cooper 1991, Turusov et al. 2002).

8.2.2.9 Tick control using acaricides

Mitigation measure: Not applicable.
Adaptation measure: Acaricides as deltamethrin control nymphes of Ixodes species (Schulze et al. 2001).
Impact on biodiversity: Insecticides may exert negative effects on non-target organisms. For example, deltamethrin has been shown to be toxic to fishes (Pimpao et al. 2007).

8.2.2.10 Tick control by vegetation management

Mitigation measure: Not applicable.
Adaptation measure: Leaf litter removal (Schulze et al. 1995), burning of vegetation (Mather et al. 1993, Stafford et al. 1998), or placement of corridors between tick infested habitats and residential areas may prevent tick population growth and dispersal.
Impact on biodiversity: Biodiversity may suffer or benefit from burning depending on the habitat and species groups. Recent literature suggests that controlled application of fire benefits biodiversity (e.g. Bunnell 1995). Indirect adverse effects on biodiversity can be expected as burning increases GHG emissions and air pollution. Leaf litter removal may prevent the regeneration of soil, and thus may alter below-ground and above-ground community composition. Placing corridors between tick-infested areas and residential areas may lead to a loss of habitats. For economic reasons forests and scrublands are more likely affected than agricultural crop lands.

8.2.2.11 Tick control by using entomopathogenic fungi

Mitigation measure: Not applicable.
Adaptation measure: Spraying spores of entomopathogenic fungi causes high mortality in tick populations (Samish and Rehacek 1999).
Impact on biodiversity: Up to now tick control by entomathogenic fungi has been applied in experimental small scale studies only (Piesman and Eisen 2008). As many entomathogenic fungi infest a wide range of arthropod hosts (Samish and Rehacek 1999) large-scale application may have negative effects on non-target organisms, e.g. insects. To assess the effects of this adaptation measure on biodiversity more research is needed.

8.2.2.12 Vaccination of rodent reservoirs to prevent the transmission of tick borne diseases

Mitigation measure: Not applicable.
Adaptation measure: Vaccinating rodent reservoirs using doxycycline hyclate

(Zeidner et al. 2004) may prevent pathogen transmission.
Impact on biodiversity: The effects on the environment are not known (Piesman and Eisen 2008).

8.2.2.13 Monitoring of pathogens and vectors

Mitigation measure: Not applicable.
Adaptation measure: Monitoring programs represent a precondition for public education programs, early warning systems and efficient pathogen and vector control.
Impact on biodiversity: Sophisticated monitoring programs may reduce the negative impacts of several vector control measures on biodiversity. For example, a pinpoint application of insecticides based on knowledge on mosquito occurrence and population dynamics may lower the impact on wetland habitats.

8.3 Discussion and conclusions

The majority of health measures refer to adaptation, whereas mitigation is rarely involved. Two measures which contain components of mitigation have been proposed to cope with heat related health problems; afforestation and the creation of green spaces within urban areas and the use of passive cooling mechanisms to lower indoor temperatures. Provided that both measures are implemented appropriately, certain components of urban biodiversity may directly benefit (Figure 8.1). Therefore, as both measures represent win-win-win situations strategies to reduce urban heat islands should be incorporated into urban landscape planning more effectively and they should be promoted in the future. Efforts to enhance the insolation of buildings also should receive adequate public support.

There are a number of adaptation measures which may lead to negative effects on ecosystems, depending on the mode and scale of application (Table 8.1). Among those measures that are considered to prevent heat stroke and heat related mortality, the active cooling of buildings is likely to express the most negative impacts on biodiversity. Considering the low standard of building isolation in many European countries, more frequent heat waves are likely to lead to increased energy use for air conditioning (Figure 8.2). An extension of air conditioning due to rising temperatures is expected to result in an increase of energy use, thus representing another adaptation strategy which is likely to result in a lose-lose situation in terms of biodiversity and mitigation (Figure 8.1). Therefore, all habitats and taxa are potentially affected by this measure.

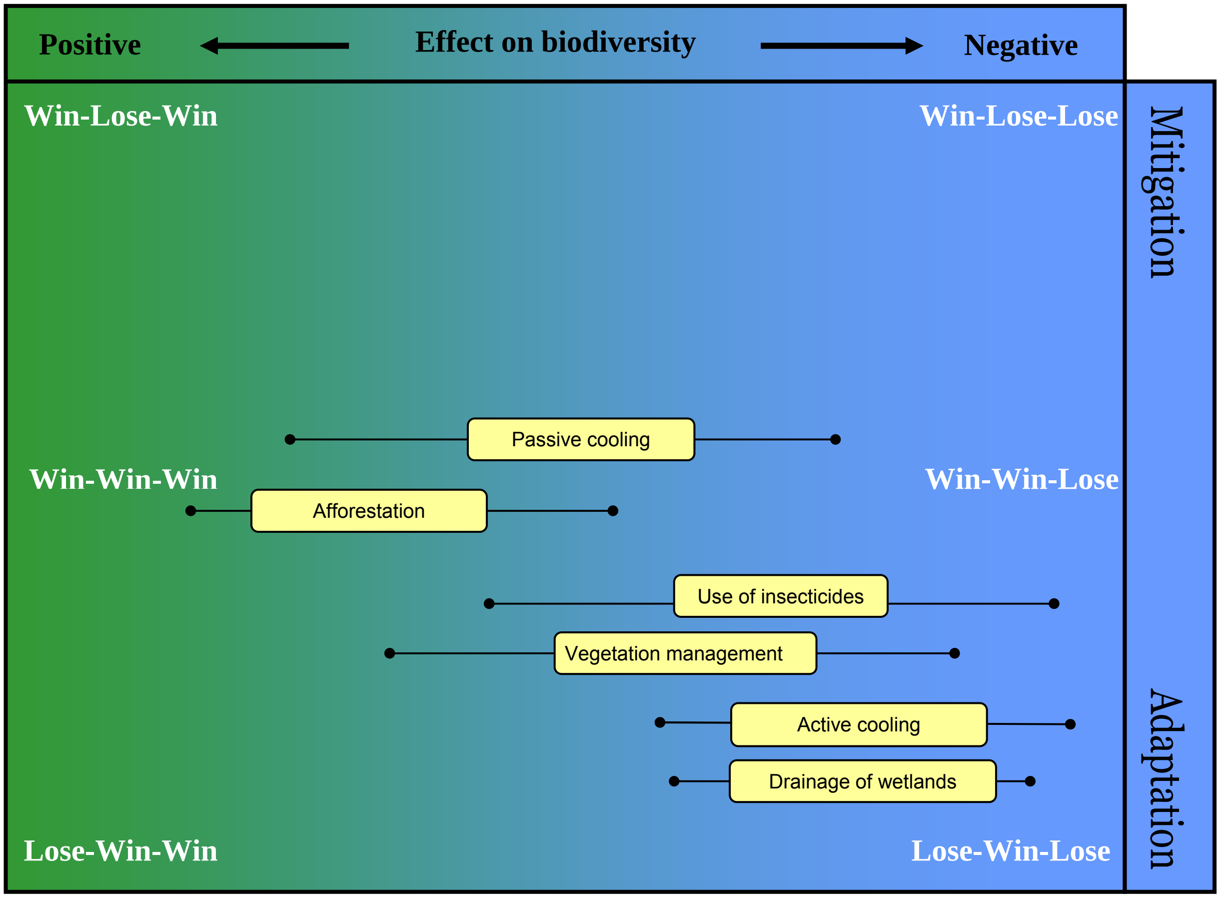


Figure 8.1: Known and potential relationships between health mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on a literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts.

Apart from few exceptions most pathogens relevant for human health are spread by mosquito vectors whose immature stages develop in aquatic habitats. Thus, wetlands and inland surface waters will be the main targets of vector control programs in the case of invasions by pathogen or vector species. The drainage of wetlands to eliminate mosquito breeding sites would certainly express the most negative effects on biodiversity because wetlands are among the most species rich ecosystems and already under threat at a global scale. The drainage of wetlands to eliminate mosquito breeding sites certainly represents a powerful adaptation measure. However, its implementation would have largely negative impacts on biodiversity and mitigation (Figure 8.1) and also on adaptation to flooding (Chapter 6). Given the high priority of wetland conservation in Europe the realisation of this measure appears unlikely (Figure 8.2).

Table 8.1: Biodiversity Impact Table.

The table summarises the impact of each measure on biodiversity. It identifies the worst-case management scenario (e.g., a careless and inconsiderate adoption of a measure) and the best-case (e.g., following good practice); it also identifies the habitats and taxa affected. The arrows indicate the degree of impact:

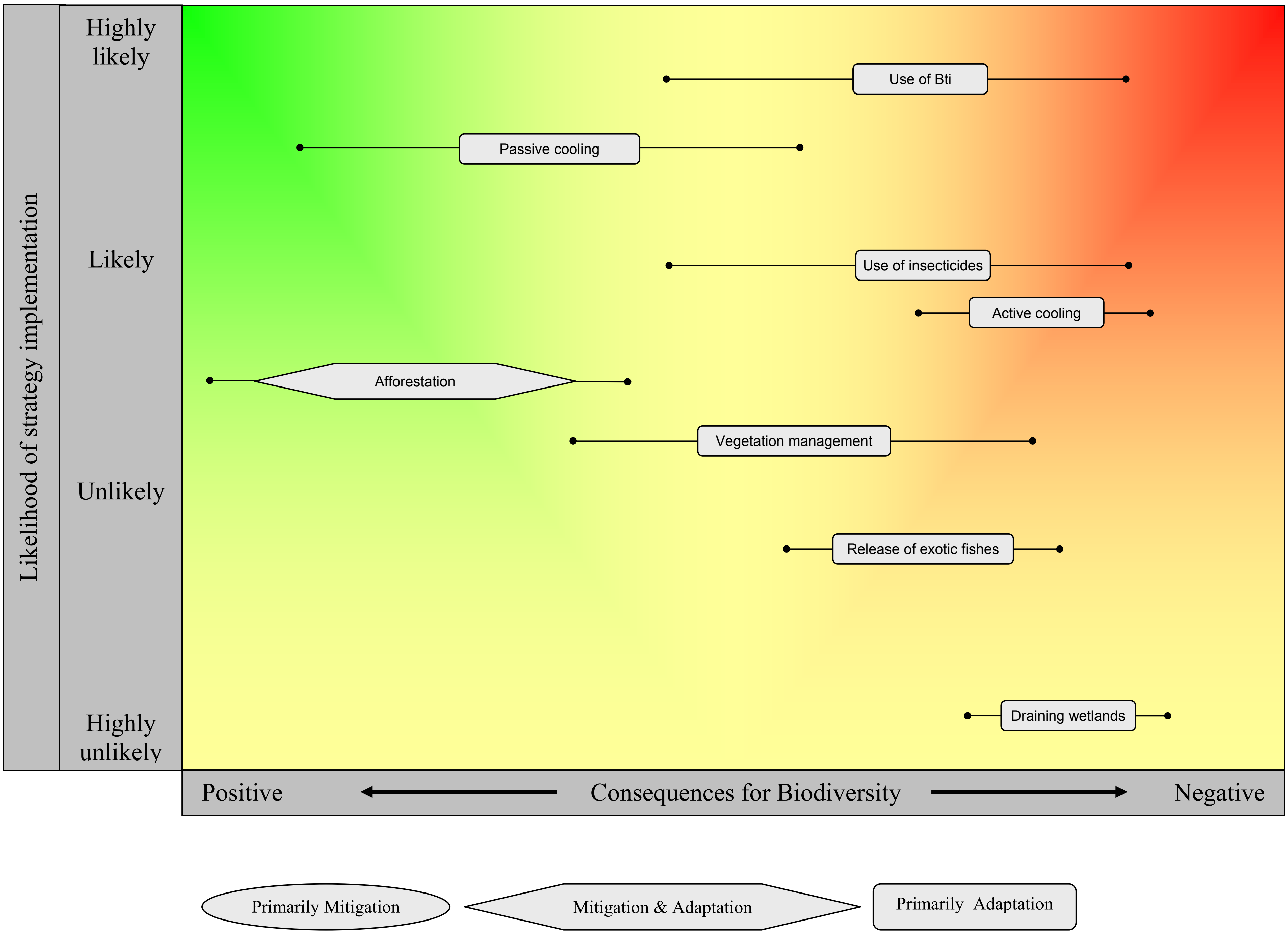
↑ Highly beneficial for biodiversity, ↗Moderately beneficial for biodiversity, ↔No known effect on biodiversity, ↘ Moderately detrimental for biodiversity, ↓ Highly detrimental for biodiversity. Habitats based on the EUNIS classification http://eunis.eea.europa.eu/habitats-code-browser.jsp?habCode=A#factsheet

Strategy	Biodiversity Impact		Habitats affected									Taxa affected					
	Impact under **inappropriate** use	Impact under **best** management practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland, forest and other wooded areas	Inland unvegetated or sparsely vegetated habitats	Regularly or recently cultivated agricultural, horticultural and domestic habitats	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants
Education programs	↔	↔															
Early warning systems	↔	↔															
Emergency plans	↔	↔															
Passive cooling of buildings	↘	↗											•			•	
Active cooling of buildings	↓	↘	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Afforestation	↗	↑										•	•	•		•	•
Surface modifications	↔	↔															
Use of insect repellents	↔	↔															
Vaccination programs	↔	↔															
Draining wetlands	↓	↓		•	•	•	•		•		•	•	•	•	•	•	•
Mosquito control by fishes	↘	↓		•	•	•								•	•	•	
Mosquito control using Bti	↘	↘		•	•	•										•	

Mosquito control using insecticides	↘	↓	•	•	•	•	•		•		•	•	•	•	•	•	
Tick control using acaricides	↘	↓			•		•	•	•						•	•	
Tick control by vegetation management	↘	↗					•	•	•			•	•	•		•	•
Tick control by entomopathogenic fungi	↔	↔															
Vaccination of rodent reservoirs	↔	↔															
Monitoring of vector and pathogen species	↔	↔	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

The use of chemical and biological control agents for mosquito control is expected to affect arthropod biodiversity in particular and is considered to have a generally negative effect because non-target organisms are affected as well (Figure 8.1). For example, there may also be direct and indirect effects on higher trophic levels such as birds and fishes. The magnitude of damage to non-target organisms generally depends on the degree of selectivity of the agent and its mode of application. Generally, microbial control agents such as Bacillus thuringensis israelensis or Bacillus spaericus affect non-target organisms to a lesser extent than chemical compounds as organophosphates, pyrethroids or DDT. However, the choice of more selective agents and their pinpoint application within integrated control schemes may reduce the risk. Assuming a further spread of potential vector species and their associated pathogens an expanded use of biological control agents as Bti appears very likely (Figure 8.2) while a broad-scale application of chemical compounds may follow in the case of emergency.

To minimize negative impacts future vector control schemes should be based on the concept of integrated biological control, i.e. the pinpoint application of biological control agents based on vector population monitoring and the facilitation of natural enemies. However, the introduction of exotic predator species for vector control should be avoided as it may lead to biological invasions having unpredictable consequences for natural systems. As the number of biological control agents is limited (Becker and Zgomba 2007) more emphasize should be put on the development of new environmentally-acceptable products. However, new techniques before applied at large scales should always pass through proper risk assessment. This is particular important considering increasing efforts to establish genetic control programs including the insect sterile technique. More research is also needed to establish species specific monitoring tools (Qui et al. 2007) as a basis for efficient integrated vector control approaches which help to prevent adverse effects on non-target organisms.



Likelihood of strategy implementation
Highly likely
Likely
Unlikely
Highly unlikely
Use of Bti
Passive cooling
Use of insecticides
Active cooling
Afforestation
Vegetation management
Release of exotic fishes
Draining wetlands
Positive
Consequences for Biodiversity
Negative
Primarily Mitigation
Mitigation & Adaptation
Primarily Adaptation

The climate change related measures in the health sector are primarily concerned with adaptation and, as has been seen elsewhere in the report, the impact does depend on the manner of implementation. This is particularly true of the various options for the control of disease vectors, where there is a high potential and risk for negative impacts on biodiversity. Care, therefore, should be taken in the selection and implementation of methods and further research carried out into less harmful means of control.

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9. Conservation

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Conservation practices lie at the heart of addressing the major objective of the UN Framework Convention on Climate Change, which is to ensure that keeping greenhouse gas emissions below a "level that would prevent dangerous anthropogenic interference with the climate system" (IPPCC, 2007). The critical role of conservation is recognised in the judgment of "safe" climate change – which recognises both food security and ecological security, namely in the phrase "such a [safe] level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, and to ensure that food production is not threatened" (IPCC, 2007). Conservation practices are aimed ultimately at minimizing the loss of habitats and species, and even genetic variation at finer scales (e.g. sub-species, ecotypes). It is precisely this variation that allows species and thus ecosystems to "adapt naturally" to change through the process of selection.

The primary strategy of conservation, namely, the establishment and promulgation of geographically fixed networks of protected areas that protects the variation of species and genetic richness, is threatened by climate change. This is because these networks will be exposed to increasingly novel climatic conditions. This is the crux of the challenge facing conservation – how to enhance the ability of tried and tested strategies that provide a basis for future species persistence under climate change.

Minimizing the loss of genetic variation, erosion of population–level richness and the possible extinction of populations and species threatened by climate change requires that populations and species be afforded the opportunity to adapt to change. Adaptation by wild species to a changing climate may happen in three ways: via species adapting on site to the new climate through changes in behaviour (acclimatization facilitated by phenotypic plasticity) and ultimately natural selection, via species moving to new sites, following the climate, or a via combination of the two processes (the most likely outcome in most cases). If the rate of climate change exceeds the rate at which these natural processes can occur, the only other alternative is decline and ultimately extinction. Wild species thus provide clear signals on whether climate change is occurring at a rate that is too high for natural adaptive processes.

Shifts of species distributions tracking changes in climate appear to be the primary way species respond to climate changes – and this is revealed in numerous records of shifts noted in the temperature-limited ecosystems of the northern Hemisphere (IPCC, 2007). This is also clear from records of the deeper past. In Northern America, beech and spruce migrated thousands of kilometres in some cases in response to post-glacial warming. Coope (1979) shows that only few beetles changed morphologically over the Quaternary, while in general species shifted considerably in distribution over this period. Other examples include the changes observed in only 3 out of 177 mammals during the Eocene and Oligocene (Prothero and Heaton, 1996) whereas changes in distributions were large. Species seem to have persisted unchanged through major climatic oscillations (e.g. Bennett, 2004), although evolution can take place in the absence of morphological change, through physiological responses (e.g. Hoffman and Hercus, 2000), the ubiquity of phylogenetic niche conservatism (Harvey and Pagel 1991; Peterson et al., 1999) indicates that the biota has typically tracked suitable climate and biomes rather than adapting readily to them.

However, while the climate history of Europe has selected species that are vagile and able to migrate rapidly (see Hewitt, 2000) the current patterns of habitat degradation and fragmentation make this tracking of optimal geographic range much more difficult (Mace and Purvis, 2008).

Current conservation strategies include little consideration of climate change, although there is a rapidly increasing realization from practitioners globally that this is needed. The science of spatial conservation has advanced much and produced a number of sophisticated tools used to locate priority conservation areas, aided by the wider availability of species distributional data. Nonetheless, these tools assume an unchanging climate and often even accept a static land use pattern. Araújo et al. (2004) showed that results of these approaches, even those aiming at large and contiguous areas, were not robust under projected climate changes and corresponding species responses.

Climate change may invalidate some familiar assumptions of conventional conservation approaches. For example, rules for reserve clustering are pertinent in situations of quasi-equilibrium between colonisations and extinctions in metapopulations. However, if extinctions are a result of shifting habitat suitabilities and species expand to new areas by colonizing environments that become increasingly suitable, then there is no logical reason to expect metapopulations to exist in any kind of equilibrium. In some cases, the so long established modern principles of conservation, may be reversed. For instance, the establishment of several small reserves that provide "stepping stones" for species tracking pertinent climatic gradients might be, in some circumstances, more politically achievable than establishing large reserves occupying climatic gradients.

There are several conservation approaches that could be enhanced to allow their contribution in different circumstances. The following measures have potential as adaptation strategies to prevent extinction of biodiversity given the predicted climate change: a) take no action through informed choice, b) adaptable conservation areas, c) focus on sound conservation outside protected areas (management of the matrix, buffers, especially through reducing other stresses on wild species), d) prevent the invasion of alien species e) manage disturbance regimes such as fire and grazing, f) expand or identify new protected areas, g) connect protected areas (corridors and stepping stones), h) conserve genetic diversity, and as a most extreme solutions, i) develop ex-situ conservation (seed banks, captive breeding), and j) translocate species in a bid to assist migration.

9.1 Take no action through informed choice

Existing protected areas have generally been established on opportunistic basis, on the lands of poor economic value and productivity. This has resulted in reserve networks, that, although together covering a substantial proportion of the Earth, do not protect current biodiversity patterns efficiently (e.g. Rodrigues et al 2004), let alone the additional needs that biodiversity will encounter under a changing climate. However, it must be acknowledged that the current investment in protected areas has been achieved and is maintained at some considerable cost, and must be a critical element of any conservation strategy into the future. Analysis of protected area and species vulnerability to climate change provides information useful for assessing where little action may be needed in response to climate change, and may also provide a hierarchy of priorities that could allow decision to be made on relative investment required – i.e. the scale of action needed based on informed choice.

Several studies have demonstrated that if we take no action and rely only on current protected areas, a large number of species are projected to disappear from them, or even become extinct globally. In 2003 the World Wildlife Fund (WWF) released a publication stating that changes in several conservation areas are already taking place and that immediate actions for including climate change in management and planning of protected areas are needed. An additional concern is the theoretical possibility of an area losing its protected status if it loses species for which it was designated, even though the area becomes important for other species colonizing it. Although not enough to halt the loss of biodiversity due to climate change, we expect current protected areas to play an important role - it will be increasingly important to assess which areas and species require relatively more investment than others, and which may receive no action through informed choice and simply not through a lack of attention.

9.2 Adaptable protected areas

A perhaps less discussed strategy to protect shifting distributions is to rely on dynamic or movable protected areas. Adaptable conservation areas mean that conservation status is applied and removed as the species or habitats of interest shift between parts of a planning region. This is not a new idea, as spatial and temporal conservation restrictions are applied in a number of circumstances, although not yet in the context of climate change. For example, they have been proposed to enable regeneration of trees in grazed landscapes (Martino, 2003) and to track species that occur patchily in space and time (e.g. Bengtsston et al. 2003). Recently, Raynfield et al. (2007) presented a sophisticated approach to demonstrate the advantages of using dynamic rather than static protected areas to maintain old growth habitat within boreal forest. Other moveable conservation areas are fixed spatially, but with temporal restrictions for example on extractive uses. These regulations are intended to protect species when they are particularly vulnerable or to enable populations to recover from harvesting. Short-term fishing closures have been applied extensively for various purposes that include protecting spawning aggregations and maintaining yields of desirable species.

Whether adaptable protected areas would be a proper approach to adapt to climate change deserves further consideration, but certainly this strategy would depend on careful monitoring and risk assessment, and decision making through informed choice. For instance, an important distinction must be made between conservation areas implemented over broad, regional scales and those protected areas implemented within multiple-use landscapes. The scale of protected areas will determine which criteria and processes should be considered during the selection procedure. At a regional-scale, protected areas may be large enough that they can maintain internal processes and accommodate shifts; hence, dynamic conservation areas at this scale are unnecessary. Nonetheless, protected areas in Europe, for instance, tend to be rather small. Allowing some of these protected areas to be re-located in response to changes in habitat quality and configuration may improve their ability to conserve target species. However, unless there is a well managed matrix between protected areas, there will rarely be suitable, good quality habitat, in which to relocate the protected area

9.3 Buffers and managing the matrix

The fixed boundaries of reserves are poorly suited to a dynamic environment unless individual areas are large (Noss and Cooperrider, 1994). Buffer zones suggested as a key strategy of the “Man and the Biosphere” program have the potential to accommodate shifting populations as conditions inside protected areas become unsuitable. For this strategy to work, buffer zones must be large. Biodiversity responses to climate change may take a variety of forms, and our current ability to predict this is limited due to uncertainties in both the climate scenarios and in how species will react to the change. Matrix management practices (referring to the matrix of managed land outside of areas under mixed land use) need to anticipate an increased movement of species through the landscape and proper monitoring should be implemented to determine where populations are shifting within the buffer.

Managing the matrix should be a complementary activity to formal conservation, rather than an alternative. If incentives can be provided to managers outside reserves to manage their lands sensitively, species will have a better chance of shifting distributions in response to climate change than if land-use adjacent to reserves is intense. For example, in South Africa already many land owners are using their land for nonagricultural activities such as ecotourism and wildlife ranching, as it provides better returns. In these circumstances, drivers of changes in vegetation structure need to be managed to best provide suitable habitat for all biodiversity, an objective that cannot be achieved without engagement by land managers (see Box 1).

There are a number of practical and ecological reasons why matrix management must be a major part of a biodiversity conservation strategy, especially when considering the impacts of climate change (e.g. Hannah et al., 2002; MA, 2006).

Matrix management to enhance resilience to climate changes can be approached in various ways, and here we emphasize two of them, both potentially needed (Von Maltitz et al., 2006):

1. Strategic conservation of critically important areas of the matrix. This would be areas that are identified as having a strategic importance for conservation, but that cannot be included into the formal conservation network for financial or other reasons.
2. General enhancements to biodiversity conservation on all non-reserve land. In this instance, less costly incentives could be used to promote more biodiversity friendly practices. Examples may involve the setting aside of riparian strips (which may also assist flood management) or woodland corridors (which could make a small contribution to carbon sequestration), reducing the use of pesticides and fertilizers, reducing animal stocking rates, or reintroducing necessary disturbances such as fire.

In any case, the area of the matrix is generally at least an order of magnitude larger than the area under conservation for most habitat types, and areas outside formal reserves generally contain a significant portion of the biodiversity. Therefore, management of the matrix can enhance not only the shifts of species through the landscape, but also promote the persistence of species outside protected areas.

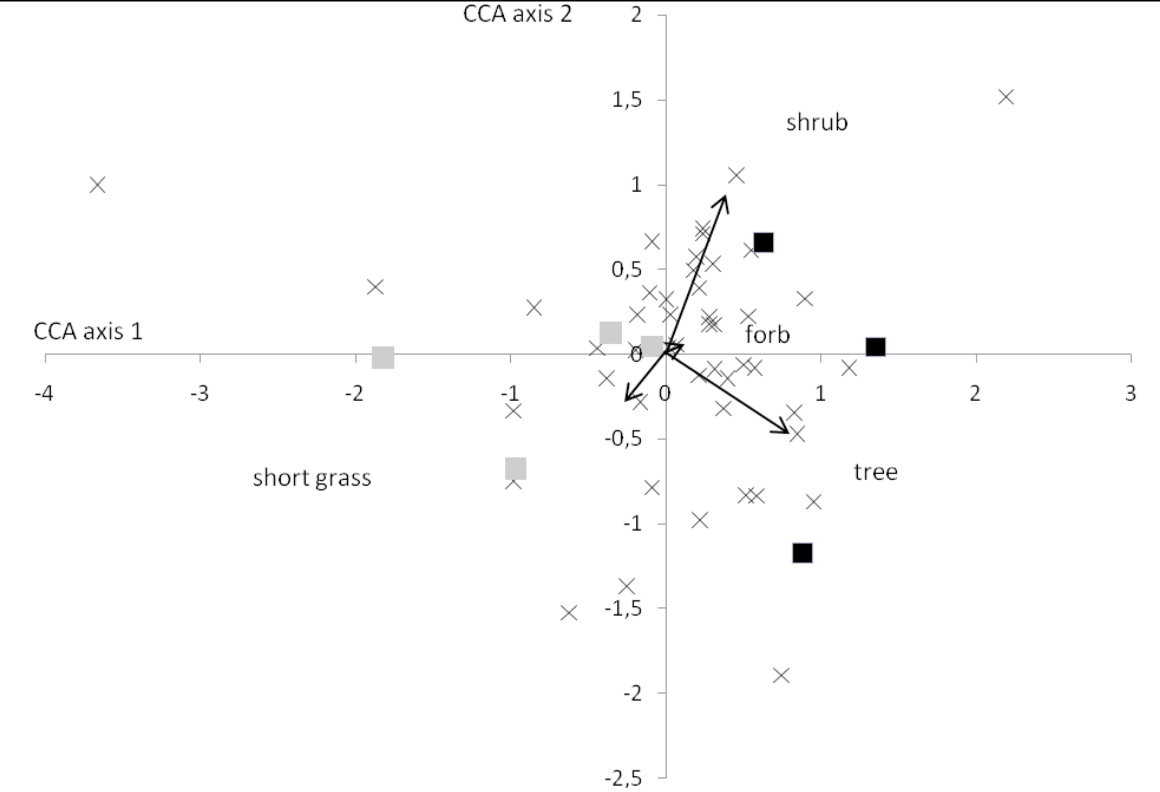
Box 1: Bird species richness responses to changing vegetation structure: insights from southern Africa on managing the matrix

While the responses of species to climate change are often modelled using a bioclimatic niche approach, it is very clear that for many animal species the structure of habitat is influential in their ecological presence and success. Changing habitat structure, either associated with or separate from climate change, is especially critical for many bird species, their community structure, and for their conservation. Responses to changing habitat may even be misattributed as responses to changing climate.

Southern African savanna ecosystems range from open grassland types to closed woodlands, with distinct bird communities. The woodiness of these systems is being altered at least partly by CO_2 fertilization of the tree component, resulting in bush and tree encroachment. This has significant implications for bird communities and for conservation strategies, and cannot be managed inside protected areas alone.

Woody cover increase has triggered a temporary increase in bird species richness due to the increase in habitat structure complexity, but it has also resulted in a dramatic species turnover. Overall, woody cover increase is ultimately likely to result in a landscape homogenization and the consequent loss of diversity for birds of open habitats as well as other groups like insects and plants. As the highest species turnover occurs during the transition from grassland to wooded grassland, management policies should target woody cover increase in open grassland types. The challenge for managers will be to find ways to maintain large patches of open savannas using a combination of tools including fire and manipulating grazing pressure. As most of the savanna bird species showing a range contraction are tied to open grassland types, the general trend of woody cover increase observed all over southern Africa raises questions for their richness and persistence into the future. For example, investment in bush clearing and fire management might be used to control this problem – with varied costs and benefits implied.

In Europe, similar changes in habitat structure may occur through land abandonment, changing fire regime and climate, to name a few possibilities.



Axis 1 and axis 2 plane of the Canonical Correspondence Analysis showing bird species scores for the study site of Rooiport Game Reserve, South Africa. Bird species symbols refer to species showing a long-term decrease at the national scale (■), species showing a long-term increase at the national scale (■) and species showing no major change (x).

Source: Sirami, SANBI, South Africa - bird responses to changing habitat structure

9.4 Prevent the invasion of invasive alien species

It is possible that the greatest beneficiaries of ecosystem disruption due to climate change will be alien invasive species that are pre-adapted due to rapid dispersal, high population growth rates, and a lack of natural enemies. A greater focus on prevention and curtailment of invasive alien species will be critical in preventing future worsening of this problem, with very complex and unpredictable implications for biodiversity. At the same time, regulations need to be adapted to account for “natural endemic” migrants that may be shifting ranges across landscapes. The issue of shifting species composition will place an increasing strain on conservation authorities who will be faced with choices about which species may be alien or endemic invasives, and there is very little theory or practical experience to draw on in this regard. This emerges as a major area of future investigation for policy purposes.

9.5 Manage disturbance regimes

In Europe disturbance is important in determining patterns of diversity, from the fire regimes of the Mediterranean and boreal forests, to the temperate grassland mowing regimes (simulating pre-modern patterns of mammal herbivory) required to maintain disturbance and plant species richness in alpine regions. Disturbance can be a useful tool in the hands of the landscape manager, but there are also threats induced by effects of climate change on disturbance regimes. In southern Europe, extreme heat and dry conditions in 2003 resulted in large tracts of forests being burned, and such events may increasingly be expected into the future. This may also bring into conflict the concerns over built assets and natural assets, such as biodiversity. These issues have been well studied in many Mediterranean-type regions of the world, but remain an area for future focus in Europe.

In the Mediterranean type ecosystems of the world, with the possible exception of Chilean matorral, wild and managed fire is a key process that may alter ecosystems in a fundamental way over a short space of time. Fire prone systems are generally adapted to fires of a given range of frequencies, and thus have even become dependent on the periodicity of this disturbance. However, the actions of humans and climate change in respectively altering the rate of fire ignitions and the climatic conditions that facilitate raise the prospect that knowledge of climate change alone is not sufficient to build robust projections of ecosystem change into the future (see Box 2).

Box 2 Understanding and projecting the impacts of fire on vegetation structure and biodiversity: Insights from southern Africa

The behaviour and role of fire is a complex area of study, here we only focus on the key question of how climate conditions that support large, significant fires may be altered by climate, and if there are ways in which these conditions can be projected using knowledge of synoptic conditions. This would be a useful first step for managers of diversity, and those managing risk of fire damage, and would provide a critical simplifying link for those modeling species diversity to reduce the complexities inherent in projecting the impacts of fire on ecosystem structure, function and biodiversity.

Our hypothesis is that synoptic conditions that support fire can be characterized (e.g. hot, windy days typified by a particular regional arrangement of atmospheric pressure states), and that these characteristic high risk days can be correlated to a high frequency of fires occurring. This hypothesis can be tested using historical fire data for a given region – in this case, the Mediterranean-climate southern Cape of South Africa. Given that this hypothesis is supported, it is then possible to project future risk of fires, and thus significant ecosystem impacts, using the outputs of General Circulation Models.

Methods

We applied a method of characterizing the synoptic state of regional climate on a daily basis using Self-organising maps (SOMS). Historical synoptic climate states are available for the region of interest for testing fire risk history over the past several decades. We also had access to an historical map of fires for the region over the past few decades. The fire data used for this study was developed from Western Cape Nature Conservation Board reserves. The fire records from four reserves where chosen for this analysis based on the length of the fire record and the size of the area over which the data was captured. The four reserves cover four distinct climatic regions, two from western, warmer areas, and two from southern, wetter areas. These climatic regions are comparable to the fire climate zones, i.e. the southern and western Cape regions, identified by van Wilgen. Fire records from the 1970s to the present were included in this study, matching the time span for which weather records are available.

Results

The synoptic range over this region could be efficiently characterized by 12 nodes in the SOM (Figure 9.1). Thus each day of the year can be represented by a node number from 1 to 12 according to its specific synoptic conditions (see Figure 1, representing the sea level pressure state characterizing each node). It is important to note that nodes do not represent a temporal progression of synoptic states; rather they are spatial archetypes of clustered data. The daily temporal progression of nodes is indicative of synoptic circulation and can follow any order (e.g. node 5→5→8→9→6); although some flow patterns are more common than others – a characteristic that is useful in predicting fire risk in advance.

Due to the nature of atmospheric circulation, some synoptic states occur more often than others. Less frequently occurring nodes indicate transitional states. The frequency distribution of each SOM node is however fairly uniform with a ~3% difference between nodes of highest and lowest frequency.

Overall, daily weather in the Western Cape is predominately affected by the South Atlantic high pressure system and frontal systems. Typical progressions of frontal systems (e.g. node sequence 2→4→7→1) indicate a front moving from west to east usually over a period of 4 days and is a common winter flow pattern. The South Atlantic high pressure dominates weather patterns in summer. Onshore movement of this system (e.g. nodes 8, 11 and 12) result in hot, dry, sunny and windy conditions. When the South Atlantic high pressure system moves offshore (nodes 3, 6 and 9), a warm tropical air mass, known as an easterly wave low, descends from the north and is associated with strong convective activity and even lightning which creates natural ignitions. It is possible to determine, using chi-square analysis, the relative likelihood of large fires occurring vs the relative occurrence of synoptic states. This analysis

(Figure 9.2) indicates firstly that there is a statistically discernible effect of synoptic state on fire risk, supporting our primary hypothesis. However, the analysis also shows that westerly, drier sites have fires that are controlled by synoptic conditions that are distinct from those that burn southerly, wetter sites.

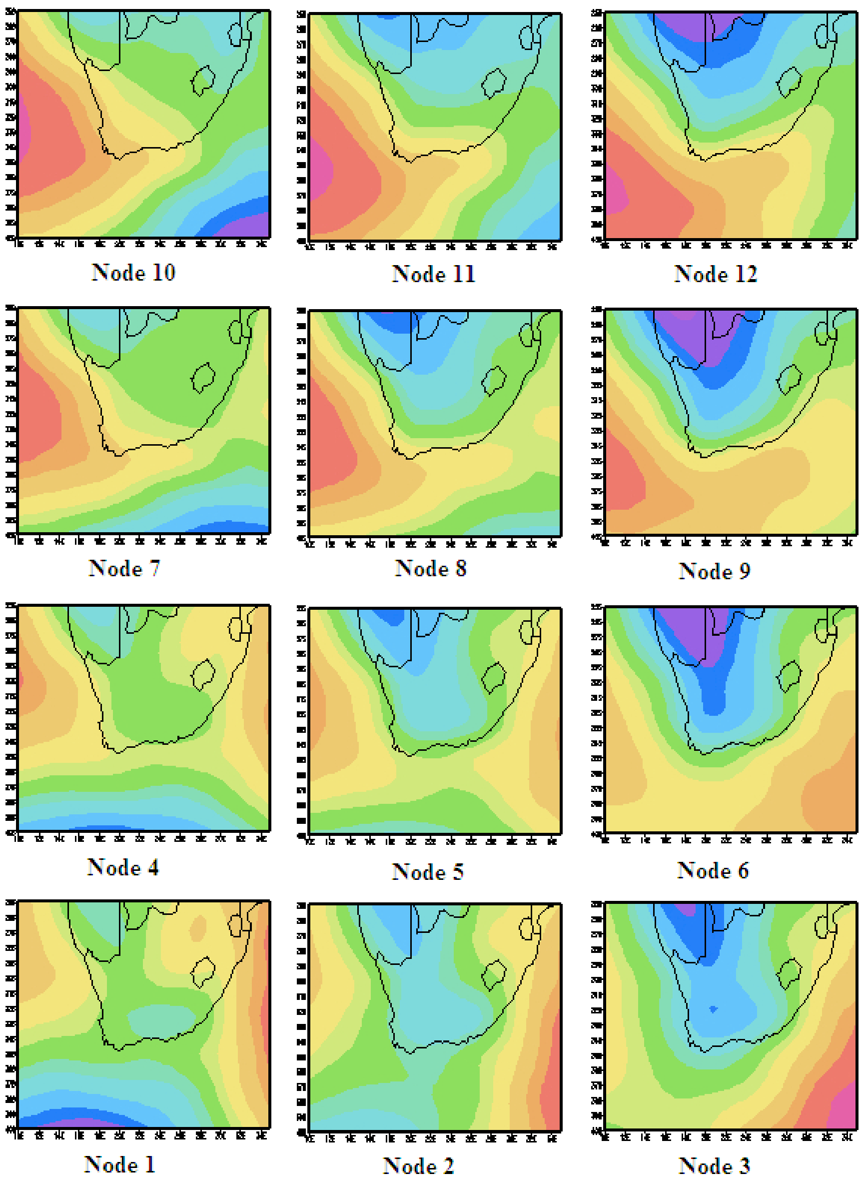


Figure 9.1. Sea level pressure conditions (red = high pressure, blue = low pressure) representing the twelve archetypical daily climatic states (nodes) that occur throughout a typical year in southern Africa, as determined by SOM analysis. Note that the numbering order does not imply any tendency for these nodes to occur in a temporal sequence, or an indication of the relative frequency of these nodes.

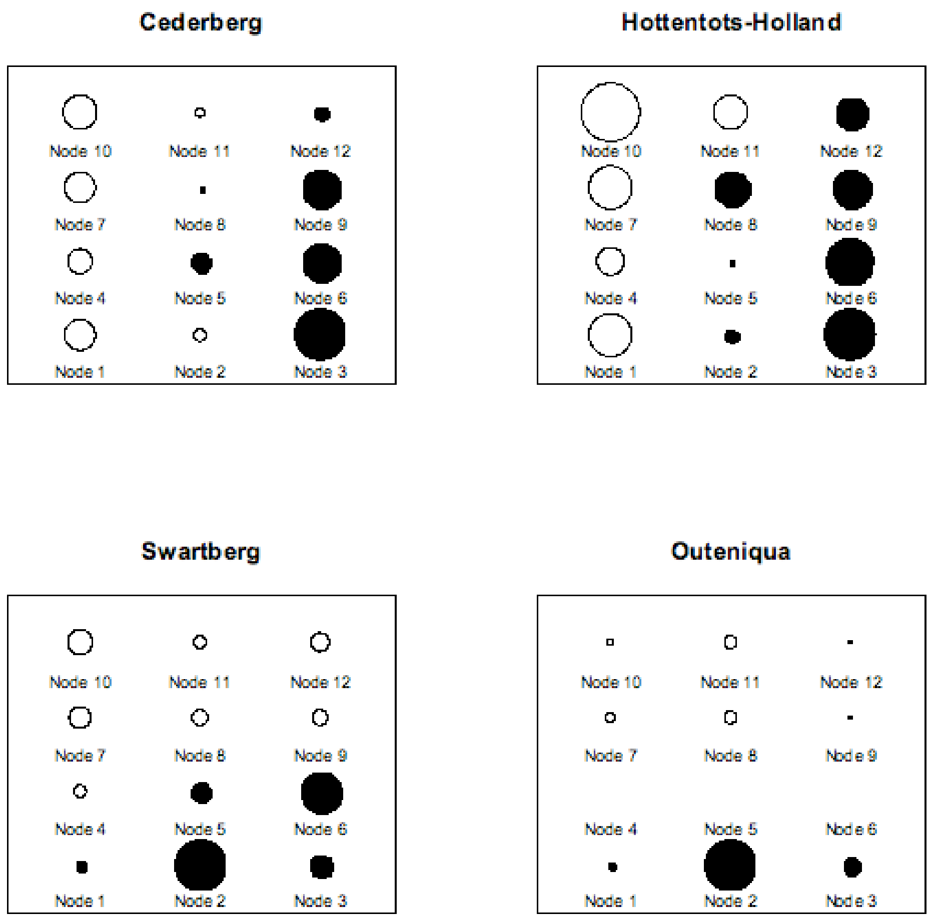


Figure 9.2. Visual mapping of the residuals of chi-squared test that discerned the occurrence of fire vs node frequency. Closed circles are positive residuals, representing a significantly higher frequency of occurrence than expected, open circles are negative residuals. Upper panels are regions of drier, westerly areas, while lower panels represent wetter, southerly regions. Implications and guidelines for management and conservation

These results indicate that knowledge of synoptic weather states provides useful early warning and predictive knowledge of current and future fire risk. This is information of interest to a wide range of managers, from those managing biodiversity to those involved in the disaster management field. This set of results also implies that the relative proportion of daily synoptic states might be used as an input to model species geographic ranges in distinct regions, and that this feature would allow a first step effort to incorporate fire risk into species bioclimatic-type modelling efforts. However, such a level of analysis requires a clear understanding of the link between synoptic states and regional fire risk – for example, in wetter southerly sites it appears that

conditions favouring natural ignitions are important in explaining fire risk, while in drier westerly regions it is conditions favouring fire spread that are more important. What is abundantly clear is that a shift in synoptic state due to climate change could have large ramifications for this key ecosystem process.
Source: Southey, SANBI, South Africa fire and climate conservation

9.6 Expand or identify new protected areas

Formal conservation areas remain a critical component for biodiversity conservation in a changing environment. This benefit can be enhanced by ensuring that reserves are well configured to best conserve biodiversity, given the impacts of climate change. The conservation of potential refugia, environmental gradients and likely migratory corridors will increase the resilience of the current reserve network facing climate change.

Systematic conservation planning has developed sophisticated algorithms to prioritize new areas for addition to the existing reserve network (Cabeza and Moilanen, 2001; Margules and Pressey, 2000, Pressey et al., 2007). The inclusion of a climate change component to such tools is, however, still in its infancy (Williams et al., 2005; Hannah et al., 2007 - see also Deliverable 3.2). Nonetheless, it is clear that existing protected areas will not be sufficient to protect biodiversity in a changing world. Where large protected areas exist, large buffer zones around them may accommodate forthcoming changes. But in most parts of Europe, protected areas are too small to accommodate changes, and the matrix around them is too modified and intensively used. Although we mention above that managing the matrix promotes the movement and persistence of biodiversity, such strategies will not be enough. Areas not yet protected, and under threat due to development pressure, may be essential for biodiversity. These novel tools are aimed at identifying which of these areas are priority conservation areas, in the context of climate change.

Additionally, as has been identified in chapter 3 (Forestry), the reduction of deforestation and increased protection of forest ecosystems is expected to be a win-win-win strategy, the most effective mitigation and adaptation strategy, which also enhances (forest) biodiversity persistence.

Refugia have retained plants and animals during times of unfavorable climate and glacial-interglacial cycles, also resulting in important centers of speciation, especially in mid- and high-latitudes (Willis and Whittaker, 2000). Such refugia are thought to be areas of special value for the long-term persistence of biodiversity. Major refugia in Europe include Iberia, Italy, the Balkans, and the Caucasus (Hewitt, 2000). Across continents, topographically diverse areas have allowed habitats and lineages to persist through elevational shifts and, in many cases, to diverge during periods of climate change (Hewitt, 2000). Climatic refugia at much smaller scales can also be important for maintaining species assemblages vastly different from those adapted to the dominant regional climate. It remains an open question whether past refugia will play similar roles in the now so fragmented landscape, and thus further research is needed to assess whether it is of importance to protect past refugia.

9.7 Connect protected areas (corridors and stepping stones)

One of the most common approaches proposed for conservation adaptation is the bridging of current protected areas with corridors (e.g. Hannah et al., 2007), in order to enhance the shifts of species following climate change. Landscape elements such as corridors, stepping stones, or barriers play a key role in conservation planning (Dramstad and Gillilan, 1996), although there is very limited evidence to show that, for example, corridors really improve functional connectivity (Chetkiewicz et al., 2006). Most of the hard evidence comes from experimental settings (Haddad et al., 2003; Levey et al., 2005) rather than from natural populations (Beier and Noss, 1998), partly because of lack of effective methods for analyzing observational data from natural populations living in heterogeneous landscapes (Ovaskainen et al., 2008). In a summary of management options for protected areas in the face of climate change, Halpin (1997) mentions buffer zones and corridors to facilitate the movement of species away from areas becoming unsuitable, but reiterates the need for firm ecological evidence upon which to base corridor and buffer zone design. In a more recent review on management options for forests in the face of climate change, Noss (2001) identifies similar priorities.

Maintaining habitat linkages parallel to climatic gradients and minimizing artificial barriers is a prudent strategy under any climate-change scenario. In the USA, biogeographic corridors, such as the Mississippi Valley and other major river valleys that trend north-south, allowed dispersal during past climate changes (Delcourt and Delcourt, 1984). The role of similar latitudinal corridors under the rapid pace of change forecasted, however, is under discussion. Noss (e.g. 2001) argues that elevational corridors, spanning a broader climatic gradient over a shorter distance, may better promote migration in mountainous terrain. Nevertheless, there are several large initiative for macrocorridors. For instance, in North America, the efforts have concentrated on the "Yellowstone-to-Yukon" wildlife corridor. In Central America, the Meso-American Biological Corridor should provide forested connections from Panama to Mexico and the IUCN envisages an uninterrupted connection between Argentina and Alaska along the hemisphere's western mountain ranges. The conservation management, habitat restoration, rehabilitation and revegetation required in developing these strategic corridors will make a significant contribution to carbon sequestration.

Noss (2001) also identifies important considerations in designing linkages:

1. A full range of geological substrates and soil types should be included in linkages because of the requirements of some plant species
2. Many species have mutualistic or other dependencies on other species, such that migration of assemblages of co-adapted species will be required
3. Because movement routes probably will vary among species, protecting broad linkages rather than narrow corridors is advised.
4. A mixed strategy of corridors and small stepping-stone habitats is desirable to address the distinct dispersal characteristics of different species

Connectivity also may help sustain genetically diverse populations, and thus promote adaptation to a changing climate.

Perhaps as important as the creation of connectors between protected areas is the minimization of fragmentation. Roads are major agents of fragmentation that pose two major problems in the context of a changing climate: they restrict the dispersal of less mobile species (Brody and Pelton, 1989: Noss and Csuti, 1997; Trombulak and Frissell, 2000, Kramer-Schadt et al., 2004), while they enhance the dispersal of invasive exotics. Closing unnecessary roads and providing wildlife crossings on roads with heavy traffic, as has been done in the Netherlands, might mitigate some of these effects.

9.8 Develop *ex-situ* conservation (seed banks, captive breeding)

For currently threatened species facing range contraction, or species with few individuals left, the only nonfatalistic option may be to maintain them *ex-situ*, in artificial settings such as zoos, botanical gardens, seed banks, and through cryopreservation, in the hope of perhaps introducing them to the wild at some future time. This approach is also an "insurance policy" for species with some hope of surviving in the wild.

Captive breeding is used to recover species that are declining in the wild. The suitability and effectiveness of such programs remains controversial, and it is in many cases a very expensive approach. Any commitment to long-term captive maintenance of a species is effectively an infinite commitment of time and resources, and probably practical only for a tiny handful of particularly charismatic species. The Amphibian Ark, is a large initiative that is collecting a selection of species that would otherwise go extinct, to be maintained in captivity until they can be secured in the wild. In some areas, this means collecting every last individual of a species, causing the extinction of a species in the wild to prevent it disappearing altogether.

One obvious concern is the negative effect that captive breeding has on genetic diversity and ultimately fitness. Even a few generations of domestication may have negative effects on natural reproduction in the wild. For instance, in steelhead trout domestication reduced subsequent reproductive capabilities by 40% per captive-reared generation. The repeated use of captive-reared parents to supplement wild populations should be carefully reconsidered.

Genetic management of captive populations via stud records is essential to ensure genetic diversity is preserved as far as possible. There are now a variety of international computerised stud record systems which catalogue genealogical data of individual animals in zoos around the world. Artificial insemination, embryo transfer and long-term cryogenic (frozen) storage of embryos represent advances in captive breeding that are expected to overcome some of the problems encountered to date. Nonetheless, the success of these techniques is limited to a number of large and charismatic species, while adequate success in captive breeding for many endangered taxa has remained elusive, despite major expenditures of resources.

Additional issues of concern include diseases and behavioural disorders, especially for vertebrates. Disease-related problems are of many sorts, from exotic diseases killing captive individuals or loss of resistance to native diseases, to the introduction of new diseases to the habitat where the species is reintroduced. Behaviour of captive-bred species is also a problem. While some behaviours are genetically determined and innate, much has to be learned from other adults, or by experience. Captive-bred populations lack the *in-situ* learning of their wild relatives and are, therefore, at a disadvantage.

A further complication is what will happen to the species' native ecosystem in the species' absence, when it has been moved to captivity. Removal of a species from a community may have unexpected consequences and alter the habitat in such a way that it is not suitable any longer for future reintroductions of the species. Due to interdependences among species in ecological communities, the loss of one species can trigger a cascade of secondary extinctions with dramatic effects on the functioning of the community. For example, the disappearance of sea otters from the Pacific coasts of North America led to the collapse of kelp forest communities, as the numbers of sea urchins increased in the absence of their predator, overgrazing their resource, the giant kelp. In turn, the disappearance of kelp led to the loss of fishes and invertebrates inhabiting the kelp forests. Similar cascading effects have also been documented in terrestrial ecosystems, for example local extinctions of wolves and grizzly bears has led to high population densities of moose that, in turn, have caused dramatic changes to the vegetation .

Similarly, climate change is reshuffling which species are found where, another reason why captive bred species that are reintroduced decades later may encounter an alien world.

Captive breeding is a relatively expensive endeavor, even when comprehensive disease precautions are not practiced. This in itself is an argument for taking great care when making decisions about when the technique should be used.

Botanic gardens throughout the world possess large living collections of flora. Whole plants, when kept *ex-situ*, have advantages in education, research and display. On the other hand, living collections have the disadvantage of high maintenance costs, including high spatial requirements. Thus, usually only one or a few genotypes are represented. Annual plants, for example, have to be subjected to frequent controlled pollination and re-establishment, unless methods of vegetative propagation are available. In addition, whole plants often hybridise with related taxa and are vulnerable to various diseases. A more promising *ex-situ* conservation approach for plants is seed-banking. Seeds are small but tough and have evolved to survive adverse conditions and attackers.

Storing seeds under frozen conditions slows down the rate at which they lose the ability to germinate. Seeds of crop plants such as maize and barley could probably survive thousands of years in such conditions, but for most plants, centuries are probably the norm. This makes seed banking an attractive conservation option. Initiatives such us the Millennium Seed Bank Project or the Svalbard Global Seed Vault aim at banking seeds from a large proportion of the world's wild plant species and crop varieties, respectively. The Svalbard seed vault is not the first seed bank in the world. There are at least 1,500 seedbanks worldwide. But some of the existing seed banks are vulnerable. The recently opened Svalbard Vault is the first one designed to stand many threats, including those posed by global warming. Permafrost and thick rock will ensure that even without electricity, the samples will remain frozen.

All *ex-situ* conservation methods discussed have their role to play in modern conservation facing climate change threats. Generally, they are more expensive to maintain and should be regarded as complementary to *in-situ* conservation methods. *Ex-situ* collections should include sufficient genetic diversity to allow adaptation to uncertain conditions in reintroduction sites.

9.9 Translocate species in a bid to assist migration

Habitat fragmentation does not allow all species to track climate change. Warren et al. (2001) evaluated changes in the distributions of 46 butterfly species with their northern climatic range margins in Britain in response to recent climate change; these butterflies were expected to have responded positively to climate warming, yet 25% of them declined, as habitat loss had outweighed positive responses to climate warming. Half of the species that were mobile and habitat generalists increased their distribution, but species of limited mobility, such as *Plebejus argus* had declined. If sedentary specialists continue to decline, and habitat connectivity cannot be improved, an alternative is to physically move the species to the new suitable habitat. Movement of large mammals and birds is a well-established practice in conservation circles. However, it is usually undertaken to reintroduce species to locations where they are believed to have occurred historically, or to increase genetic exchange. Introduction of species to places where they probably did not exist within the recorded past, or where the climate might be suitable but the resources or the community might be different has enormous risks. Assisted migration will have ethical and practical considerations, including the risk of increasing the vulnerability of a species already close to extinction and the risk of introducing a species that may become an invasive in a new community. By studying past invasions, comparing those of intracontinental origin to those of intercontinental origin, Mueller and Hellman (2008) show that, although the former have been less frequent, they have been as severe as the latter. This indicates that no assisted migration program will be risk free. According to past invasions in the United States, assisted migration for fish may be risky, while it may be more useful and safer for plants plants.

McLahlan et al. (2007) raised an important debate, noting the risks associated with this strategy. Successful translocations would require the identification of a) species that are more or less acceptable to translocate, b) sites that are more or less acceptable for receiving translocations, and c) projects that are more or less acceptable because of their socioeconomic ramifications and feasibility. Hunter (2007) reviews candidate species, candidate sites and feasibility.

What makes a species a candidate for translocation depends on their probability of extinction due to climate change, their mobility, and their ecological roles. If climate change can be identified as the main factor of threat, it makes sense to act before a species is in serious trouble. Nonetheless, so far it has proved to be hard to disentangle threat factors. Prime candidates are species that appear unlikely to disperse and colonize on their own. Note that dispersal here means intergenerational movements, and for example, a wind-dispersed plant can be considered more dispersive than a migratory sea turtle that is highly philopatric (Hunter, 2007). Furthermore, translocation of species that have major ecological roles is riskier than translocation of those which are more redundant (e.g. moving a dominating tree species would more likely have a dramatic effect than moving an uncommon forest herb). The Torreya Guardians (see e.g. McLachlan et al., 2007), see the assisted migration of the Florida Torreya as the only alternative to save this plant from extinction, as there are only few individuals left, which are no-longer reproducing, and therefore not dispersing, and climatic forecasts predict a shrinkage of the suitable habitat.

For candidate sites a major issue is the amount of disturbance. One would not want to disturb a pristine site, while would not mind introducing the species in a very disturbed site, when keeping in mind potential negative consequences for the community at the candidate site. However, species translocations would rarely be successful in very disturbed sites. Similarly, moving species into a well-connected site that has experienced major changes in species composition as species have shifted their ranges in response to natural climate change would be far more acceptable than using a site that has long been an 'island', because isolated sites will be more likely to harbor a unique biota. On the other hand, one would prefer to treat translocations as experiments, and a recently isolated site, embedded in a highly altered matrix, may provide a good setting, diminishing the potentially negative or unacceptable effects of an introduced species.

Additionally, although still controversial, studies on invasion of ecosystems by exotic species and the relationship between stability and diversity (Hooper et al., 2005) suggest that a species-rich ecosystem may be less likely to be disrupted by a translocation than a species-poor ecosystem.

There are a large number of uncertainties and risks in the translocation of species. A proper decision framework should be looking at whether translocation of the species is essential, achievable (economically and technically) and safe (Hoegh-Gulberg et al. 2008).

9.10 Conclusion

By definition, conservation is a sector with actions that should have a positive impact on biodiversity. However, conservation following 'business as usual' can have negative impacts. There are a number of conservation actions, such as increase in protected area, sustainable management of the matrix, or management of processes such as fire that can have important climate change mitigation potential. The rest of strategies reported here are adaptation measures. Some of them, while benefitting some species, may have secondary consequences affecting biodiversity negatively, and thus are associated to higher risk (fig 9.3.). Others offer safer benefits, but all are associated to a great degree of uncertainty. All these measures are being or will very likely be applied (fig. 9.4), but some of them represent larger risks for biodiversity, while others may offer safer benefits (see Impact table below). Additionally, some strategies may be of general application (such as extend protected areas, define buffers around protected areas) while others can be applied only in critical situations or for particular taxa (translocate species to assist distribution shifts). Several of the proposed activities, although with great potential, they are too general to be applied, and require specific plans, risk assessments and monitoring.

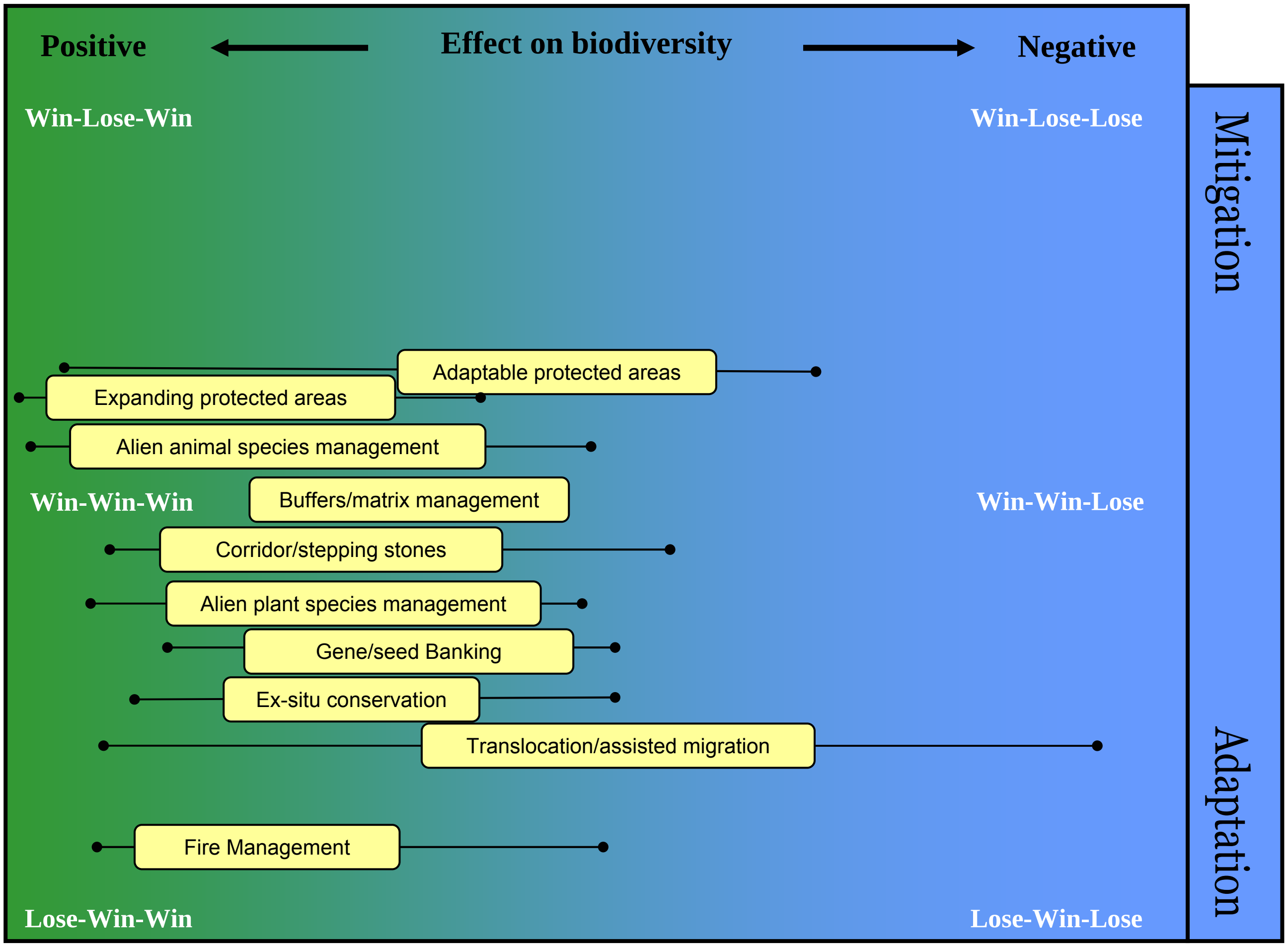


Figure 9.3: Known and potential relationships between mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on a literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts. For example, not all afforestation projects are the same: monoculture plantations with high water demands could have detrimental effects; encouraging natural regeneration around existing species-rich woodland could be beneficial. The order of win/lose 'trilogies' is Mitigation-Adaptation-Biodiversity.

9.10.1 Biodiversity Impact Table

The table below summarise the impact of each measure on biodiversity. It identifies the worst-case management scenario (e.g., a careless and inconsiderate adoption of a measure) and the best-case (e.g., following Good Practice); it also identifies the habitats and taxa affected. The arrows indicate the degree of impact:

Conservation Mitigation or Adaptation Strategy	Biodiversity Impact		Habitats affected									Taxa affected					
	Impact under worst practice	Impact under best practice	Marine	Coastal	Inland surface waters	Mires, bogs and fens	Grasslands and tall forb habitats	Heathland, scrub and tundra	Woodland and other wooded areas	Unvegetated or sparsely vegetated habitats	Agricultural, horticultural and domestic habitats	Mammals	Birds	Amphibians/ Reptiles	Fish	Invertebrates	Plants
Movable protected areas in space	↘	↗	●	●		●	●	●	●			●	●	●	●	●	●
Adaptable protected areas (esp. moveable in time)	↘	↗	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Buffers around protected areas	↘	↗	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Managing the matrix	↘	↗	●		●	●	●	●	●	●	●	●	●	●	●	●	●
Stepping stones and corridors	↘	↑	●		●	●	●	●	●	●	●	●	●	●	●	●	●
Refugia	↔	↑	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
New and expanded protected areas	↔	↑	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Assisted migration	↓	↗		●	●	●	●	●	●			●	●	●	●	●	●
Seed banks	↔	↗		●	●	●	●	●	●			●	●	●	●	●	●
Captive breeding	↓	↗	●	●	●	●	●	●	●			●	●	●	●	●	●
Gene banks	↔	↗	●	●	●	●	●	●	●			●	●	●	●	●	●
Invasive alien control	↓	↔	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Disturbance management fire	↓	↗				●		●	●		●	●	●	●	●	●	●
Disturbance management grazing/mowing	↘	↗					●	●	●	●	●	●	●	●	●	●	●

9.10.2 Research needs

The conservation actions exposed here are generally common sense recommendations reflecting what is prudent in the face of paramount uncertainty about the responses of biodiversity to climate change (Noss, 2001), but also include suggestions that may be seen as novel, and that may increase the financial and capacity of current conservation networks. Sound conservation should anticipate changes, and thus decisions rely on forecasts, while focusing on careful monitoring for policy relevant guidance, and increasing knowledge and capacity to cope with the more extreme potential outcomes of climate change. Major challenges for conservation planners are thus, to embrace forecasts in the planning process, and to build a monitoring program that can test these forecasts prudently. This is because projections of biodiversity responses still rely on relatively simple models, and our understanding of processes that will be impacted by climate change remains limited. Improving this understanding through research is vital, but also, the incorporation of proper risk assessments and uncertainty analyses is essential. Research needs include developments in a number of fields:

- Higher-resolution models of the direction, magnitude, and rate of climate change within regions.
- Empirical research on the details and mechanisms of biotic change in response to climate change at the edges of species' ranges, including the role of disturbance, alien invasive species and rising atmospheric CO_2.
- More precise determination of the biomes, vegetation types, species, and sites that are most vulnerable to adverse effects of climate change, based on extended monitoring, experiments and modelling exercises
- A better understanding of the role of species interactions in determining the responses to climate change
- Long-term monitoring with an experimental design adequate, at least, to determine correlations and, ideally, to determine causality between changes in climate parameters and responses of biodiversity
- Further work in the identification of indicators (species and otherwise) that will provide an early warning. This indicators need to clearly respond to climatic changes and not be affected by other pressures in place.
- Controlled experiments to assess the risks and benefits of assisted migration, learning from advances in invasives science
- Further understanding of the role of past refugia during past climate changes.

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10. Synthesis of interactions between mitigation, adaptation and biodiversity

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10.1 Introduction

Chapter 2 to 9 have examined for eight sectors the evidence for the impacts of adaptation and mitigation measures on biodiversity. These were based on a review of readily available literature and while both grey literature and peer-reviewed articles were examined it is not likely to represent the full evidence available. These results, therefore, will need to be refined continually as further evidence comes to light.

Nevertheless, they do provide clear over-arching messages of the potential for mitigation and/or adaptation measures to be complementary or antagonistic (Chapter 1) and to either contribute to or detract from biodiversity and thus affect conservation efforts. This is illustrated in Figure 10.1, where the feedback of mitigation and adaptation measures onto climate change impacts can be seen. This also shows that while from a climate change perspective mitigation activities have a more global effect, from a biodiversity perspective mitigation measures can have a significant regional/local impacts. These impacts are from where the win-win-win results can come.

10.2 Mitigation and adaptation measures and biodiversity

Some of the mitigation and adaptation measures have no recorded effect on biodiversity, although this may as result of lack of knowledge. For example, many of the animal husbandry and breeding measures appear to have no direct effect (Table), nor do some ways of managing flood losses (Chapter 6), or health adaptation measures, such as vaccinations and education (Table) or energy-efficient appliances or buildings (Chapter 5). In these cases they can be considered appropriate neutral measures with regard to biodiversity. The ideal goal should be to identify those situations where there are wins for mitigation, adaptation and biodiversity, that is win-win-win measures and policies, but firstly some different sectoral examples of the positive and negative relationships between, mitigation then adaptation and biodiversity will be given before examining inter-actions between mitigation and adaptation and biodiversity.

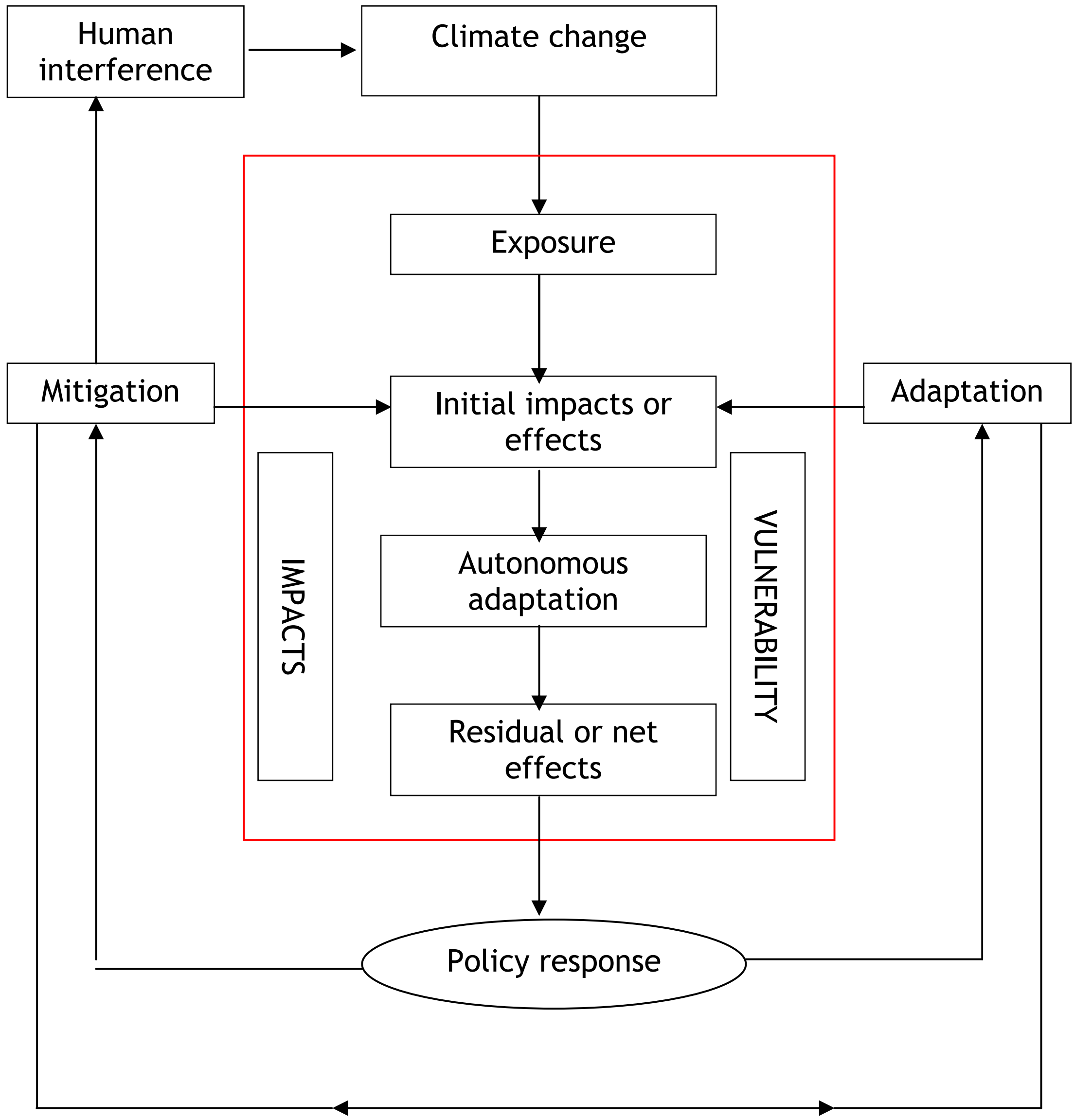

Figure 10.1: The inter-relationship between adaptation and mitigation. The red box represents a sector, in this case biodiversity (Adapted from *Smit et al.*, 1999).

10.2.1 Mitigation

In terms of mitigation it is possible to identify measures in all sectors which directly contribute positively to biodiversity. For example, in the agricultural sector which involves many mitigation measures, the better management of slurry can reduce greenhouse gas emissions and also reduce the likelihood of runoff and many land management options can be positive for biodiversity. (Chapter 2). Similarly reduced deforestation can maintain carbon sequestration and help prevent habitat loss and fragmentation (Chapter 3). In contrast, all energy mitigation measures are at best neutral to slightly negative for biodiversity, while dams and tidal barrages have the potential to be most detrimental (Chapter 4). In agriculture, grassland improvements (Chapter 2) and in forestry (Chapter 3), renewable woody biomass, are other examples of largely negative impacts. Mixed biodiversity responses to mitigation measures can come from afforestation, which can be positive on degraded land and some abandoned pastures, but negative if it involves the conversion of natural or semi-natural habitats. This measure may contain an adaptation element if provenances from a wide range of localities are used (Chapter 3).

10.2.2 Adaptation

In a similar way it is possible to identify adaptation measures which enhance biodiversity, although, in the case of energy, measures have little impact on biodiversity and opportunities to enhance it appear lacking (Chapter 5) and for the ski industry most adaptation measures are detrimental (Chapter 8). For river and coastal flood management the measures identified are all concerned with adaptation, as mitigation is not a short-term solution to the problems of flooding, although there may maybe mitigation benefits associated with some of these measures, such as the restoration of wetlands. Positive adaptation measures identified in the various sectors include: the use of nitrogen efficient or drought efficient cultivars (Chapter 2); many urban green spaces and the modification of channel geometry to decrease flow rates thus benefiting species which require slow flowing water (Chapter 6). Conservation adaptation measures, if appropriately applied, should all enhance biodiversity. Many of those measures in other sectors which are positive, involve the restoration of more naturally functioning ecosystems and thus the services which they provide, in terms of river regulation for example.

Some adaptation measures, however, could be negative for biodiversity, such as the control of mosquitoes by draining of wetland and/or the use of chemical sprays (Boisvert and Boisvert 2000; Turusov et al. 2002; Confalonieri et al. 2007 – Chapter 7) and the greater use of artificial snow in ski resorts snow-making or their transfer to/ development at higher altitudes (Chapter X). Often the impacts on biodiversity are mixed, depending amongst other factors on how the measure is implemented, the location and habitat or taxa being considered. In the case of conservation, for example, the development of ecological networks may aid the spread of undesirable (invasive or pest) species (Chapter 9).

10.3 Interactions between mitigation, adaptation and biodiversity

The above illustrates that some measures can have a mitigation and adaptation component and thus there are possible interactions between them, as discussed in the introduction and as illustrated in Figure 10.2. Those which involve both mitigation and adaptation and are positive for biodiversity include some land conversions (Chapter 2), green roofs (Chapter 5), unmanaged coastal realignment and wetland (re-)creation for flood management (Chapter 6). These represent win-win-win situations. Other combinations, such as improvement of forage quality however lead to win-win-lose situations, so while there may be reduced methane emissions and maintained/increased animal productivity in unfavourable periods, the decline of unimproved grassland would be negative (Chapter 2). Mixed biodiversity responses appear common when measures involve both mitigation and adaptation, such as the conversion of arable to pasture (Chapter 2) or the planting of fast-growing trees (Chapter 3) are considered. These mixed responses show the variable nature of impacts of the measures and means that inter-related factors, such as location, scale and management need to be taken into account.

10.3.1 Location

Firstly, location is important as it affects exposure to climate change, the consequent impacts and thus whether adaptation is required in order to cope with or reduce these impacts. In the built environment (Chapter 5), for example, only certain towns and cities will be exposed to severe heat stress or

Secondly, location can affect the appropriateness of different adaptation measures to be employed and, more importantly in this context, the impacts of those measures. On the coast, the nature of the coast will affect the need for adaptation and options available. Re-alignment (Chapter 7.2.2) can only occur where there is adequate space behind. Chapter 4 suggested that increased bioenergy production on a landscape scale can be positive or negative. In homogeneous landscapes with low biodiversity value increasing the heterogeneity will have positive effects for biodiversity (Benton et al., 2003); conversely, the conversion of semi-natural habitats to bioenergy would likely have the opposite effect (Koh, 2007; Groom et al., 2008; Firbank, 2008). The impacts on biodiversity vary greatly also depending on the scale and design of the project. Land use change (Chapter 2) is another example of where design and location is important. In most landscapes and careful positioning of land-use conversion will be required to achieve full biodiversity potential (Van Der Horst and Gimona, 2005), but generally the conversion of arable to other land uses is positive, especially the addition of semi-natural habitats in homogeneous landscapes. In the energy sector (Chapter 5), the location of the particular measure can be important. The impacts of windfarms on

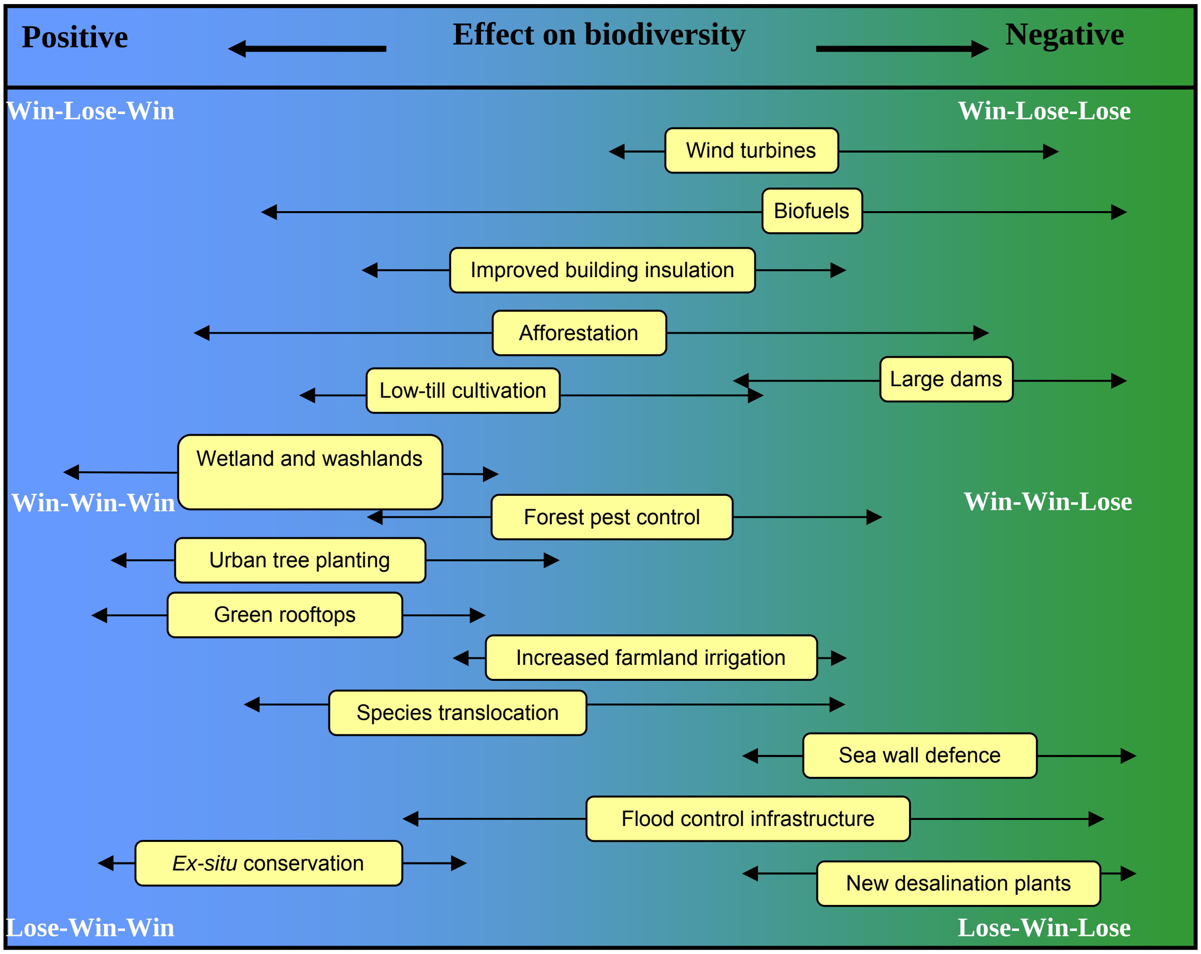

Figure 10.2: Known and potential relationships between mitigation and adaptation measures and their impacts on biodiversity. The position of the boxes on the biodiversity axis is based on the literature review of the biodiversity impacts of various mitigation and adaptation schemes and represents the typical outcome; the whiskers demonstrate the potential range of impacts. For example, not all afforestation projects are the same: monoculture plantations with high water demands could have detrimental effects; encouraging natural regeneration around existing species-rich woodland could be beneficial. The order of win/lose 'trilogies' is Mitigation-Adaptation-Biodiversity (from Paterson *et al.*, 2008).

10.3.2 Scale

Many of the mitigation measures are at a larger spatial scale than those associated with adaptation. Large scale biomass plantation projects like oil palm plantations in Malaysia, Indonesia, and Thailand (Chapter 3) should be avoided if biodiversity is of prime concern, as they entail the destruction of large areas of rainforest, reducing biodiversity, increasing vulnerability to catastrophic fires, and affecting local communities dependent on services and products provided by forest ecosystems. In the case of many renewable energy measures scale is important. The environmental effects resulting from the manufacture and operation of solar technologies, for example, are, in comparison to other energy sources, quite minimal and designed and implemented in the right way would be almost have no impact. Large-scale plants, however, can compete for land-use with marginal or semi-naturals lands and water use can be high, which can have negative impacts on local ecosystems (Chapter 4). Hydropower schemes are similar, in that the impacts on biodiversity vary greatly depending on the scale, design and the location of the project. Run-of-the-river schemes are far less detrimental to river and landscape biodiversity than large-scale hydro schemes (Bakis, 2007), but even they are not without impacts (Chapter 4). Spatial scale is also important for protected areas, as size will determine which criteria and processes should be considered during the selection procedure. At a regional scale, protected areas may be large enough that they can maintain internal processes and accommodate these shifts; hence dynamic conservation areas are unnecessary at this scale (Chapter 9).

There is less specific information available on the effect of time on the impacts of mitigation and adaptation measures. In agriculture, wetter winters may force farmers to adopt more spring-sown crops which would have positive effects for biodiversity through the proliferation of over-winter cereal stubbles which provides valuable habitat and food source for a range of insects and birds. In river and coastal flooding, the residency time of water on flooded areas can affect the type and degree of impact on biota (see Chapter 6: Introduction). In the case of low defence structures, it was noted that they can increase the connectivity between natural rocky reefs thus increasing the gene flow within a species (Chapter 6.2.1.2). This can be negative since it can reduce local adaptation within a species and thus, on a larger time scale, decrease the evolution of new species. They can also provide new dispersal routes that permit the invasion of non-indigenous species, including pests. The same could be true of measures to increase ecological connectivity (Chapter 9).

In some cases, the spatial and temporal scales may be linked, as seen in the potential impacts of hard defence construction (Table 6.1), with many local effects being short to medium term, while regional effects generally were longer term. In this example, some detrimental effects on biodiversity became apparent over this longer time scale.

10.3.3 Management practice

Sometimes best practice with regards to adaptation and mitigation can lead to greater detrimental impacts on biodiversity, but often management practices are not uniformly implemented and many are case/location specific. For example, for the various means of flood water storage, such as detention ponds and bunds (6.1.2.1) and wetlands and washlands (6.1.2.1), the flood duration, flood seasonality and wetness conditions in the washland are the key factors that determine the potential type and quality of the habitat (Morris et al., 2004), with the habitat potential mainly depending on land and water management practices beyond the flooding period, especially the management of groundwater levels.

In agriculture, the use of winter cover crops is widely advocated as a viable mitigation technique and may also provide useful adaptation benefits in wetter winters (e.g., soil stabilisation); in some parts of Europe where winter stubbles are commonly found their loss to a green cover crop may result in loss of biodiversity (e.g., birds species dependent upon stubbles). In these instances, individual tailoring of any mitigation scheme will require careful consideration of each farm’s biodiversity.

From a conservation perspective then measures which produce wins for biodiversity should be encouraged, but these may not be the most effective for adaptation or mitigation and thus while complementarities should be sought, trade-offs often will need to be made. Sustainable development advocates have pushed for a climate change policy approach that puts development at the forefront, with equal attention to mitigation and adaption (Bradley et al, 2006). Similarly, viewing potential mitigation and adaptation actions through a biodiversity “lens” may help identify wins for all three and ensure that conservation issues do not get lost in the flood of inputs that usually deluge policymakers in this arena.

10.4 Habitats

It is difficult to generalise about the habitats affected by the mitigation and adaptation measures as it is partly dependent on the sector under consideration. For example, agriculture primarily directly impacts agricultural and grassland habitats, while coastal flood management mostly affects coastal and marine habitats. In many cases, what is more important is the degree and nature of the habitat management. This was highlighted through, for example, for urban parks and gardens and for wetlands and reflected in the worst and best management practice columns in the summary tables at the end of each chapter.

Many habitats of conservation concern at both the international and national level could be affected by mitigation and adaptation measures. For example, measures in the skiing industry will particularly affect montane habitats especially grasslands, including some listed under the Habitats Directive. Similarly, tidal barrages (Paterson et al., 2008) and other coastal flood management schemes will impact on protected saltmarsh and coastal grazing marsh and there is a question over whether the latter could be replaced by more sympathetic management of inland grazing marshes. Also of concern are measures, such as air conditioning and desalination which, through increased energy usage, will feedback into climate change and thus have a more global impact.

On a more positive note, the recognition of the importance of biodiversity as a component in (eco)tourism and the role of forests in providing cooler environments for recreation could lead to some synergies with adaptation and/or mitigation.

10.5 Taxa

In many cases knowledge on the impacts of mitigation and adaptation measures on taxa is limited or non-existent. It is also difficult to generalise about the impacts, with most being sectorally or measure specific. Many agricultural activities, however, directly affect plant diversity which in turn affects insect, bird and mammals. This trophic cascade effect is important to be aware of particularly if the target taxa has numerous knock-on effects and conflicts can occur. In the case of agriculture it was pointed out that while the use of winter cover crops to mitigate GHG might provide excellent habitat and feed opportunities for insects, small mammals and birds; however, populations of ground-nesting or granivorous birds that rely upon over-winter stubbles may be adversely affected (Chapter 2). The measures' impacts also differ according to their method of implementation, location and site management. Indirect effects will be felt through changes in their habitat, both quantity and quality.

As with habitats, species listed under the EC Birds and Habitats Directive could be affected, with mitigation and adaptation measures offering both opportunities to strengthen conservation objectives, as well as possible threats. This research review though has served to highlight where these possible synergies and conflicts might exist and which measures could be deployed to the benefit of different stakeholders.

10.6 Integration and cross-sectoral issues

The world is often divided up into sectors for pragmatic policy planning and management reasons. Only more recently has the need for a holistic approach to environmental issues been re-identified (Convention on Biological Diversity, 2006). The world of adaptation and mitigation measures is no exception and a Canadian report on climate change impacts and adaptation which examines seven sectors says “It must be emphasized that these sectors are both interrelated and interdependent, in that adaptation decisions undertaken within one sector could have significant implications for other sectors.... It is therefore important to coordinate adaptation activities between sectors.” (Government of Canada, 2004, pix). The UK Government has recognised that adaptation is a cross-Government issue and it is one of 13 cross-cutting themes in Defra (Defra, 2008).

In the preceding chapters individual mitigation and adaptation measures have been identified, but in reality a combination of them may be implemented in order to deal with a particular situation and these may be entirely within any sector or may involve cross-sectoral impacts and actions. An example of the former is the Netherlands Room for the Rhine Branches (RfR) project which sought, primarily at a national level, to find ways of accommodating discharge from the Rhine within the dike system (Silva et al, 2001). A whole range of adaptation measures were considered and implemented, including the prevention of new development on the flood plain of the relevant rivers, lowering of the flood plains by excavation combined with nature development, lowering of groynes, lowering of the low flow channel and setting back the dikes. The need to do this was prompted by the 1993 and 1995 floods, but the situation has been partly brought about by changes higher up the Rhine and thus a full integrated river basin management approach, as promoted by the Water Framework Directive and Floods Directive is critical. Generally river catchment management recognises the need to integrate environmental economic and social issues within the basin into any strategy or plan and integrated catchment management has a similar underlying philosophy and seeks to maximise sustainable benefits while safeguarding natural resources. Both will require the involvement of other sectors such as agriculture, conservation and urban planning and design.

The cross-sectoral nature of mitigation and adaptation measures is shown in Figure 10.3, where climate change impacts on all sectors producing specific impacts and responses. These, however are all interacting as shown by the two-way arrows between the red sectoral boxes. Water is a good example of a cross-sectoral adaptation issue involving sectors such as agriculture, tourism, energy, biodiversity, navigation and flood management. The Canadian report on Climate Change Impacts and Adaptation (Government of Canada, 2004) illustrates this well with an example of water supply in the Great Lakes region (Figure 10.4). Water was not covered in MACIS and in the IPCC Technical paper on Climate change and water, which deals with a number of sectors, interestingly ecosystems and biodiversity is the only one for which there is not a section on Adaptation, Vulnerability and Sustainable Development (IPCC, 2008).

Some of the major cross-sectoral mitigation and adaptation measures identified in this report are given in Table 10.1. For example, managed re-alignment, is often driven by flood and coastal defence strategies and/or habitat creation plans, but it also provides social benefits including increased areas of natural habitats for recreational use such as cycling, fishing walking bird watching, as well as opportunity to develop educational facilities related to nature conservation (Pontee, 2007). Similarly urban green and blue infrastructure can provide recreational opportunities. Other interactions, such as urban intensification, energy usage and heat stress, may not be so positive and may involve trade-offs between sectors. It can also involve trade-offs between different types of habitats e.g. salt marsh and coastal grazing marsh. Chapter 7 identified that there are many areas of interaction between construction and the built environment and other sectors, particularly transport, energy and water use. The location and design of housing, for example, has a significant impact upon the transport flows generated, energy usage, water demand and flood potential. In relation to the latter setting up of the New York biosphere reserve was partly motivated by the need to manage extreme events, especially storm water flooding (Solecki and Rosenweig, 2004) and sustainable drainage systems (SuDS) may offer significant opportunity for biodiversity protection and improvement. Mata and Budhooram (2007) examine the options for the integration of mitigation and adaptation management actions in the water sector and show how they can be complementary.

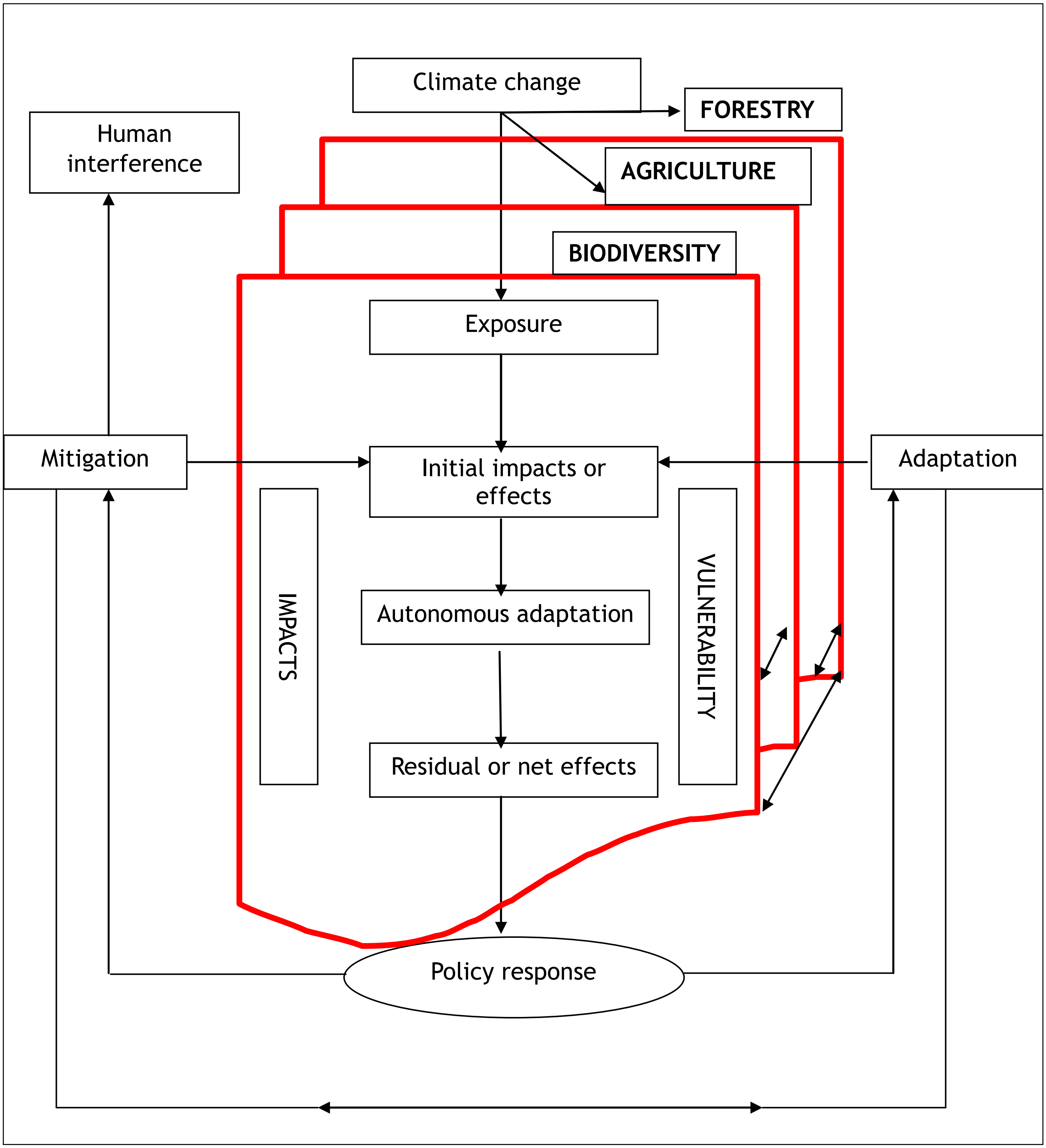

Figure 10.3: The cross-sectoral nature of mitigation and adaptation measures, illustrated here by reference to biodiversity, agriculture and forestry. (Adapted from *Smit et al*., 1999).

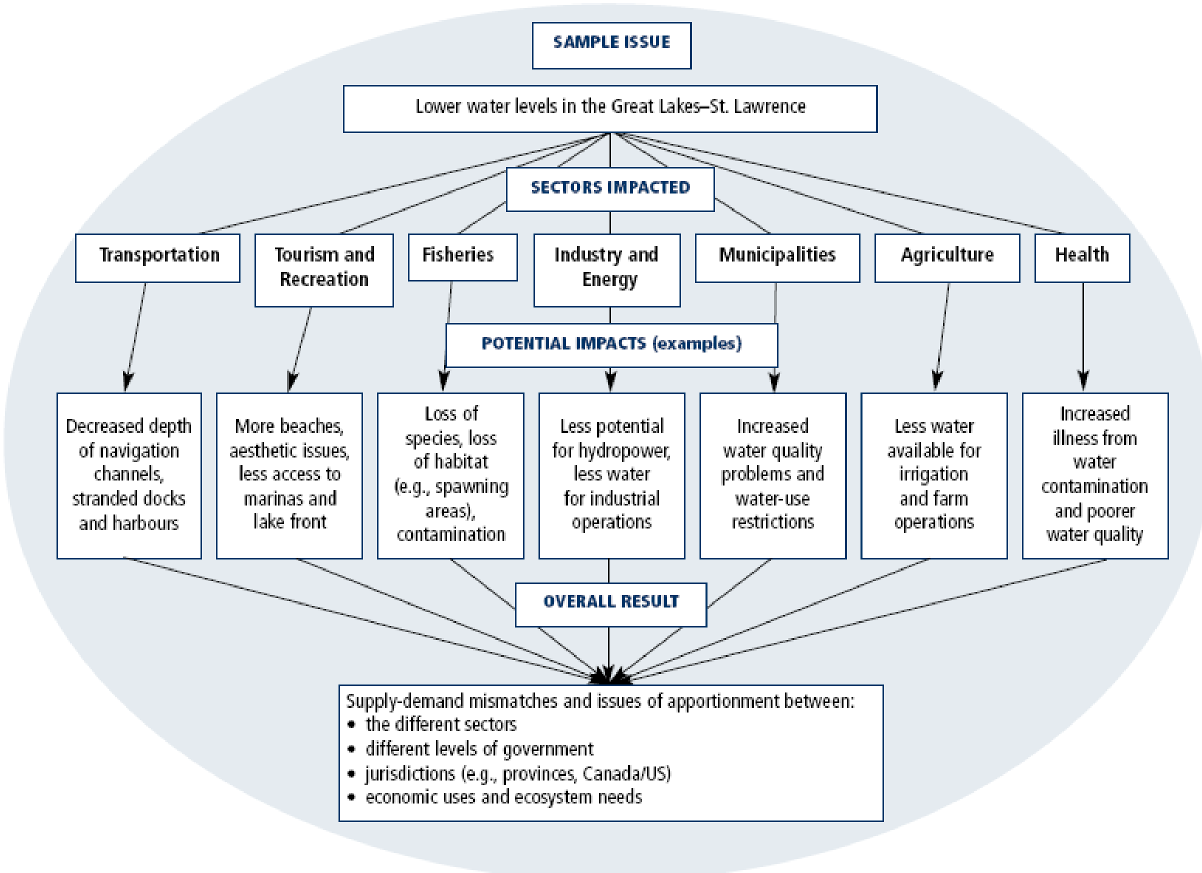

Figure 10.4: Water resources as a cross cutting issue (from the Canadian report on Climate Change Impacts and Adaptation, Government of Canada, 2004).

Bioenergy is another example of a mitigation strategy that crosses sectoral boundaries. To start with, the agricultural and energy sectors are directly involved, but it in some circumstances the presence of woody biomass plantations may also reduce the effects of flooding on local housing and may have beneficial effects if situated next to conservation areas too.

The IPCC (Adger et al., 2007) and the Finland National Adaptation Plan12 also recognise the need to take cognisance of adaptation in other parts of the world and changes elsewhere that could affect adaptation. Changing patterns of tourism and leisure, for example, could lead to northward shifts in holiday destinations (Hamilton et al. 2005), as parts of southern Europe become too hot. The patterns also could be influenced by economic and social changes, such as changing preferences. An analysis of such factors is beyond the scope of this report, but it is an area that needs further investigation.

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	Agriculture	Forestry	Energy	Built environment	Flood management	Tourism & leisure	Health
Forestry	Reduce or precision use of fertilisers may reduce fertility load in adjacent woodland.						
Energy	Adoption of biofuel cropping as alternative to traditional energy sources	Adoption of woody biofuel as alternative to traditional energy sources					
Built environment		Urban expansion could lead to loss of forest and/or fragmentation	Increased energy usage e.g. with air conditioning. Possible micro generation of energy.				
Flood management	Changing tillage practice can reduce runoff. Dikes and embankments - protect farmland from erosion. Coastal realignment- loss of farmland.	Afforestation may reduce flooding	Tidal barrages and wave energy converters - green energy and may offer some coastal protection	Dikes and embankments - protect settlements from erosion. Flood management can be part of urban and building design. Possible increase in impermeable surfaces			

	Agriculture	**Forestry**	**Energy**	**Built environment**	**Flood management**	**Tourism & leisure**	**Health**
Tourism & leisure	Reduction in livestock numbers may affect access to and aesthetics of popular tourist landscapes.	Increase in forest cover reduce risk of avalanche and rock fall in mountain resorts. Shade providing forests may attract more tourists	Change in travel mode from air and car to coach and rail	Blue and green infrastructure provide opportunities for recreation.	Structures affect views and leisure activities. Wetlands offer opportunities for recreation.		

Health	Some mosquito control measures e.g. the use of insecticides may prevent the spread of vector species which transmit human and livestock pathogens, vegetation management for tick control may lead to a loss of agriculturally used land	Afforestation may reduce the urban heat island effect, vegetation management for tick control may lead to a loss of forrest area	The use of nuclear power bears the risk of radioactive contamination of humans, biofuels may be produced at the expense of food production increasing the risk of malnutrition	Urban landscape planning and building design may reduce the urban heat island effect	Dikes and embankments protect settlements from flooding and may prevent casualties, the creation of green spaces within urban areas may enhance flood protection. Some measures e.g. dentention ponds can improve water quality, including the reduction of disease agents. Drainage of wetlands for vector control would be negative for biodiversity	Mosquito control e.g. by Bt toxines may increase the attractivity of wetlands for leisure activities	
	Agriculture	**Forestry**	**Energy**	**Built environment**	**Flood management**	**Tourism & leisure**	**Health**

Conservation	Numerous connections: 1-abandonment of agricultrual land could be highly beneficial; 2-reduction in agrochemical use would benefit adjacent conservation areas.	Continuous cover forestry offers less disturbance for wildlife Creation of firebreaks in woodland natural reserves may harm biodiversity. New species used for forestry may be invasive in woodland nature reserves.	Renewable energy schemes requiring large areas of land or water (hydro, tidal, wind) may destroy nature reserves or have negative downstream effects.	Increase in green spaces. Tree planting for shade.	Dikes and embankments - protect reserves from erosion but loss of coastal grazing marsh. Coastal realignment - loss of coastal grazing marsh. Dredging for sediment for beach nourishment - loss of marine organisms, but could create dune systems	Matrix management an increase or creation of new protected areas could enhance the tourism and recreational potential of an area	Increase of open space or afforestation to reduce the urban heat island effects on health could be beneficial. Introduction of vector control agents - benefits questionable

Table 10.1: A selection of cross-sectoral mitigation and adaptation measure interactions.

10.7 Uncertainty

There are many sources of uncertainty in such a review, some of which stem from those surrounding future climate change projections, especially in the longer term and thus the level of mitigation and adaptation required. The observed impacts attributable to current climate change, discussed in the introduction mean that mitigation and adaptation are now more critical responses.

This review has shown that there is a lack of knowledge of the impacts of some mitigation and adaptation measures on biodiversity as a whole and some habitats or taxa in particular. This uncertainty is reflected in the "whiskers" on the figures in the sectoral chapters showing the impacts of mitigation and adaptation measures on biodiversity and in Figure 10.2, and in the opportunities and risks figures, and tables of the varying impacts under different management practices at the end of each chapter. This means that the transfer of "best practices" should be undertaken with caution in order to ensure their applicability to a new situation. For example, the widespread adoption (whether through financial incentive or legislation) of low-emission livestock housing systems may well be an effective mitigation measure without many biodiversity consequences in many farms; however, if it entailed the destruction or modification of old, traditional farm buildings it is far more likely to be harmful to many bird (e.g., barn owl) or bat species. On a positive note, this impacts uncertainty does show that in some (many) circumstances it should be possible to reduce the impact of a particular measure by careful implementation that is appropriate to that location.

Also, at the moment the magnitude of unintended consequences between mitigation and adaptation is uncertain (Adger et al., 2007) and they do not take impacts on other sectors into account. Thus there is uncertainty in cross-sectoral responses, especially where there are antagonisms between or trade-offs between particular measures.

10.8 Research needs

Many studies on mitigation and adaptation identify research needs (e.g. Government of Canada, 2004; Adger et al., 2007) and some of these are relevant here. In addition, each sector chapter in this review has identified research needs. Some may be unique to that sector, but there are general or recurring needs which are identified below:

1. Greater knowledge of the impacts of some mitigation and adaptation measures on biodiversity, especially:
    i. under different management practices;
    ii. on a wider range of taxa in any given situations;
    iii. on the effects that may occur if invasive species are facilitated;

iv. on ecosystem functioning and services;
v. on the differences between short-term and long-term consequences for biodiversity and ecosystem services.

2. More research on the cross-sectoral aspects of measures, including their impacts, inter-relationship and inter-dependence.
   i. Good illustrative regional and cross sectoral case studies.
   ii. Better analytical frameworks for identifying and evaluating the links between mitigation and adaptation and particularly extending to secondary effects e.g. on biodiversity.
   iii. Guidance in the application of mitigation and adaptation measures and their cross-sectoral linkages in the realms of policy and decision-making.
   iv. Better understanding of the interactions between climate change mitigation and adaptation measures and responses actions to other non-climatic stresses.
   v. Integration with social and economic consequences of the implementation of mitigation and adaptation measures.
   vi. The effects strategies in Europe have on countries in other parts of the world (is there a 'footprint'?)

Research in the above areas would help to address some of the uncertainties identified earlier.

In order to identify risks then it has been recommended that regions and sectors considered to be most vulnerable, as well as on climate changes that would pose the greatest threats to human systems, such as extreme events or those that would lead to the exceedance of critical thresholds should be given priority (see Government of Canada, 2004).

10.9 Cross-sectoral Policy

The cross-sectoral nature of mitigation and adaptation measures (Figure 10.3 and Table 10.1) means that in order to have coherent responses there needs to be policy integration between in the various sectors. The EEA (2005) and this project (Piper and Wilson, 2007) have examined policy developments promoting biodiversity conservation in various sectors. An assessment of recent changes in policy in these sectors (at a national level) would be needed to know for certain whether there was significant policy development to adapt to climate change impacts on biodiversity. The EEA reports particularly focus on Environmental Policy Integration (EPI) in EU member states (EEA 2005a, b), as EPI is a process to ensure that environmental issues are reflected in all policy making. These concluded that there have been very few policy changes specifically targeted toward adapting to the impacts of climate change on biodiversity in Europe (EEA, 2005a, b). The EU White Paper on Adapting to Climate change in Europe, however, should initiate further integration of adaptation to the impacts of climate change on biodiversity into all policy sectors and the EU could ensure that mitigation and adaptation issues (including their environmental consequences) are adequately integrated into such policies as the EIA and SEA directives. The policy context and options for mitigation and adaptation measures, however, is discussed in more detail in the next chapter.

10.10 Conclusions

This review has shown how there are a variety of possible interactions between sectoral mitigation and adaptation measures, and between these and biodiversity. The nature of these interactions can depend on the location, temporal and spatial scale of the measure and the manner of its design and implementation. Those which are particularly negative or positive have been identified and their likelihood of implementation assessed. Thus the opportunities for and risks to biodiversity can be recognised and appropriate strategies can be undertaken which, ideally, achieve the win-win-win trilogy.

Many of the mitigation and adaptation measures are cross-sectoral in implementation and impact, so an integrated approach is required, in order to achieve maximum benefit for all concerned. A generic framework for identifying the inter-relationships between mitigation and adaptation measures, both within and between sectors is being developed, based on the win-win-win trilogy and more case studies would help in testing this. There are uncertainties and gaps in our knowledge, but there is a need to promote win-win-win situations and avoid/minimise those which pose high risks in order to maximise the efficiency and effectiveness of the measures being taken to address climate change.

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