IPCC WG II Fourth Assessment Report − Draft for Government and Expert Review

Chapter 4 – Ecosystems, Their Properties, Goods, and Services

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Executive Summary

- Principle findings of the TAR remain relevant, but with more evidence and greater confidence from a broader ambit (high confidence; 4.4.1-4.4.11) that identifies substantial species and ecosystem vulnerabilities especially to temperature changes in excess of 2 degrees above pre-industrial levels (high confidence; 4.4.11). New concerns have emerged, including possible impacts of wildfire in terrestrial ecosystems (high confidence; 4.4.1), and ocean acidification in the marine realm (high confidence; 4.4.9).
- Climate change impacts may occur earlier than projected by TAR, such as negative impacts on global terrestrial carbon balance after an initial net gain until ~2030, induced mainly by impacts on forest systems turning the biosphere into a net carbon source (medium confidence; 4.4.1. 4.4.11) and there is growing evidence for a high vulnerability of a larger fraction of species (globally ~25% by 2100, for some biota as low as 1% or as high as 43%) becoming committed to extinction than previously assessed (medium confidence; 4.4.11).
- In addition to widespread species geographic shifts (high confidence; 4.4.11) major (high confidence) and rapid (low confidence) shifts in vegetation structure (medium confidence; 4.4.1, 4.4.10, 4.4.11) are possible in most regions (not only in the boreal zone as previously stressed) some driven by wildfire, and other ancillary stresses (medium confidence; 4.4.1) which may lead to mainly detrimental changes in ecosystem services (medium confidence; 4.4.1, 4.4.3, 4.4.4, 4.4.5, 4.4.6, 4.4.10, 4.4.11).
- Responses of endemic species geographic range size are overwhelmingly negative (high confidence; 4.4.11) with resulting impacts on biodiversity and biodiversity hotspots (medium confidence; 4.4.10), and strongly sensitive systems such as coral reefs (high confidence; Box 4.5; 4.4.9) arctic systems (high confidence; 4.4.6), mountains (high confidence; 4.4.7) Mediterranean-climate systems (medium confidence; 4.4.4) and savannas (medium confidence; 4.4.3).
- In many cases, endemic species persistence requires migration rates that exceed their natural adaptive capacity (for tree species high confidence (4.4.5), other species medium confidence, 4.4.11). These effects, combined with landscape fragmentation through land use change, limit natural adaptation especially for plant species, and increase their risk of extinction during this century (medium confidence; 4.4.1-4.4.6, 4.4.11). Marine ecosystems and species appear more able to shift range rapidly than many terrestrial species (medium confidence; 4.4.9).
- Changes in disturbance and other ancillary stresses such as wildfire and invasive species are likely to exacerbate climate change impacts, sometimes synergistically (medium confidence; 4.4.1).
- Conservation entities are generally poorly prepared (with a few exceptions of untested theoretical developments) for climate change impacts, especially if based solely on static protected areas systems (high confidence; 4.4.11, 4.6.1).
- The cascade of uncertainties from climate change projections (especially in rainfall patterns) through still developing theory and knowledge of species to ecosystem responses (high confidence; 4.4.1, 4.4.11, 4.8) remain significant barriers to developing coherent and detailed regional planning responses, thus responses remain limited to generalized no-regrets strategies (high confidence; 4.6), and impacts on sustainable development and livelihoods are difficult to estimate (high confidence; 4.7).

4.1 Introduction

The critical role of ecosystems in supporting human well-being is now beyond doubt (Millennium Ecosystem Assessment, 2005b), and the importance of ecosystem persistence under anthropogenic climate change is recognized in Article 2 of the UNFCCC. Humans have historically benefited from well known ecosystem-derived goods, but ecosystems also provide a range of equally important services that underpin human well-being in less well recognized ways through regulation of global carbon, nitrogen, water, and other biogeochemical cycles and global, regional and local environmental conditions.

4.1.1 Biomes, communities, population systems, and ecophysiology

For the purpose of this assessment an ecosystem is defined as a functional entity consisting of interacting groups of organisms and their environment. Ecosystems cover a hierarchy of spatial scales and can comprise the entire globe (e.g. global biogeochemistry), biomes at the continental scale, or small, well-circumscribed systems such as a single vernal pool. Thus, this chapter considers the response to climate change of functional and structural properties of ecosystems, their goods and services and their underlying biodiversity for biomes and communities, populations, the underlying ecophysiological processes and any emergent biogeochemical impacts.

The focus is on natural ecosystems (Table 4.1) from the global to local scales as grouped by commonly accepted functional classifications and based on projections of future impacts for the scenarios from WG I (physics) and chapter 2 (scenarios). Certain ecosystem goods and services are treated in detail in other sectoral chapters: chapters 3 (water), 5 (food, fibre, fisheries), 6 (coasts), and 8 (health). Key findings from this chapter are further developed in the synthesis chapters 17 to 20. Region-specific aspects of ecosystems are discussed in chapters 9 to 16.

Projecting the impacts of climate change on ecosystems is complicated by an uneven understanding of time and spatial scales of response because these scales are often linked. Processes at broad spatial scales are characterised by long-term temporal responses (decades to millennia), i.e. the biosphere (ecosphere) at the global scale (centuries, millennia), biomes at the continental scale (decades to millennia), and large assemblages of organisms forming communities at the regional scale (years to centuries). Conversely, responses of species and populations sometimes of putative keystone or indicator species, show intermediate temporal responses (months to centuries) that underpin changes in biodiversity. Finally, fast ecophysiological responses (seconds, hours, days, months) of micro-organisms, plants, and animals operate at microscopic scales from a leaf or organ to the cellular level, and are assessed here if they scale up to have a significant impact at broader spatial scales, or where the mechanistic understanding assists in assessing key thresholds in higher level responses.

Biomes are assemblages of organisms with a characteristic structure that is repeated at broad spatial scales in similar climatic zones throughout the world. They are the result of long-term, self-organizing processes such as the formation of soils, development of disturbance regimes, and a balanced nutrient capital. Thus climate change is expected to trigger responses that may last up to millennia before biomes reach a state of dynamic equilibrium with respect to their biophysical and chemical environment.

The distribution of biomes has traditionally been explained only in terms of climate control (Schimper, 1903), but several recent findings agree that disturbance regimes such as fire or insects, may influence vegetation structure significantly. Biomes are differentially sensitive to climatic change (e.g. Kirschbaum and Fischlin, 1996; Gitay *et al.*, 2001; Sala *et al.*, 2000), with temperature-limited biomes prone to impacts of warming, and water-limited biomes prone to increasing levels of drought. Some biomes such as fire dependent biomes, may be in a meta-stable state that can fairly rapidly switch under climate and other environmental changes (Bond *et al.*, 2005; Scheffer *et al.*, 2001).

Table 4.1: *Major ecosystems addressed in this report, together with their global areal extent, NPP and total carbon stores (above plus below ground, compiled from 1 – Sabine et al., 2004; 2 – Bonan, 2002; 3 – Field et al., 1998; 4 – Hassan et al., 2005 Table C2; 5 – Mitra et al., 2005 Table 2, Figure 4; 6 – Foley et al., 2005), and brief listing of key goods and services.*

Biome / Ecosystem	Area (Mkm^2)	% transformed	NPP (Pg C y^{-1})	Plant Carbon (Pg C)	Soil Carbon (Pg C)	Ecosystem services
Deserts	[1] 27.7	[4] 3.5	3.2 [3](1.5)	[1] 10	[1] 208	Pasture, food, medicinals, eco-tourism, biodiversity of drought- and heat-adapted life forms, extraction of fossil fuels and water, military and recreation activities
Grasslands and savannas		[4] 28.6	[3] 19.2			Livestock production, wood production for fuel and construction, plant, mammal and bird diversity, carbon sequestration, soil protection.
Tropical grassland/savanna	[1] 27.6		[1] 13.7	[1] 79	[1] 345	Nature-based tourism, mammal and bird diversity, Livestock production, wood production for fuel and construction, carbon sequestration, soil protection.
Temperate grassland	[1] 15		[1] 5.1	[1] 6	[1] 172	Carbon sequestration, soil protection.
Mediterranean ecosystems	[1] 2.8		[1] 1.3	[1] 17	[1] 124	Biodiversity, wildflower and other extractive products, water yield, soil protection.
Forests and woodlands			[3] 26.9			Timber and non-wood products, ecotourism, food, medicinals, biodiversity, soil/water conservation, carbon sequestration, recreation, research opportunities, spiritual/cultural values
Tropical forests	[1] 17.5	[4] 34	[1] 20.1	[1] 340	[1] 692	Biodiversity, ecotourism, carbon sequestration and regional climate amelioration
Temperate forests	[1] 10.4	[4] 67	[1] 7.4	[1] 139	[1] 262	Timber and non-wood products, carbon sequestration
Boreal forests	[1] 13.7	[4] 25	[1] 2.4	[1] 57	[1] 150	Carbon sequestration, regional climate amelioration
Cultivated lands[3]	[4] 35.3	[4] 47	38	-	?	
Tundra, other palearctic biomes	[1] 5.6	[4] 0.3	[1] 0.5 [3](0.8)	[1] 2	[1] 144	Carbon sequestration and climate regulation, biodiversity of low-temperature adapted species, fuel, food and fibre, cultural and spiritual values
Freshwater lakes, rivers, wetlands	[4] 10.3	[4] 11	-	-	-	Freshwater supply, aquatic biodiversity, nutrient transport, pollution amelioration
Inland wetlands, peatlands	[5] *3.5-4.0*		[2] 3.8	[5] ~8	[5] 225-462	Carbon sequestration, biodiversity, fuel
Terrestrial ecosystems	148.2	[6] ~40	53.7 ([3] 56.4)	658	2322-2559	
Marine ecosystems	[4] 349.3	-	[3] 48.5	-		Food, carbon sequestration, biodiversity, regional climate control, waste dilution, recreation, spiritual and cultural value
Total	497.5	-	102.2 ([3]104.9)	650		

Communities are found at a level below biomes and are characterized by a specific species composition and thus a specific diversity.

Population systems are usually characterized by a particular species and may cut across communities and even biomes, e.g. many migratory birds inhabit forests or grasslands – depending on the season – and visit wetlands on their migratory routes.

Ecophysiological responses operate continuously, at a microscopic scale, and usually represent the initial response of individual organisms to environmental variability. Ecophysiological mechanisms underpin individual tolerance to environmental stress, and comprise a broad range of responses. Thus ecophysiological responses define the absolute tolerance limits of individuals to environmental conditions, and may scale up to control species geographic range limits, and even ecosystem functions at a regional and global level. Possibly the best example of this is the role of leaf stomata, whose behaviour in regulating water flux scales from individual leaf, to impacts through canopy to regional and even higher levels of ecosystem organization (Hetherington and Woodward, 2003; Gedney *et al.*, 2006; Matthews, 2006).

4.1.2 Ecosystem goods and services

Ecosystems provide many goods and services (Fig. 4.1) that are of vital importance for the functioning of the biosphere as a life-support system, and provide the basis for the delivery of tangible benefits to human society. Some of these, such as water purification and pollination, are well known, but others, such as carbon sequestration (e.g. Foley and Ramankutty, 2004), are less obvious and often hardly recognized, yet they are vital for human welfare. Some ecosystems services are not of direct use to humans yet are a necessary prerequisite for all goods and services of interest to humans. These are termed supporting services, and comprise the processes resulting in soil formation, local climate modifications, nutrient cycling, all of which are needed for primary and secondary ecosystem production (Fig. 4.1). Critically moreover, ecosystems maintain biodiversity, an increasingly valuable resource that underpins many of the goods and services humans enjoy from ecosystems.

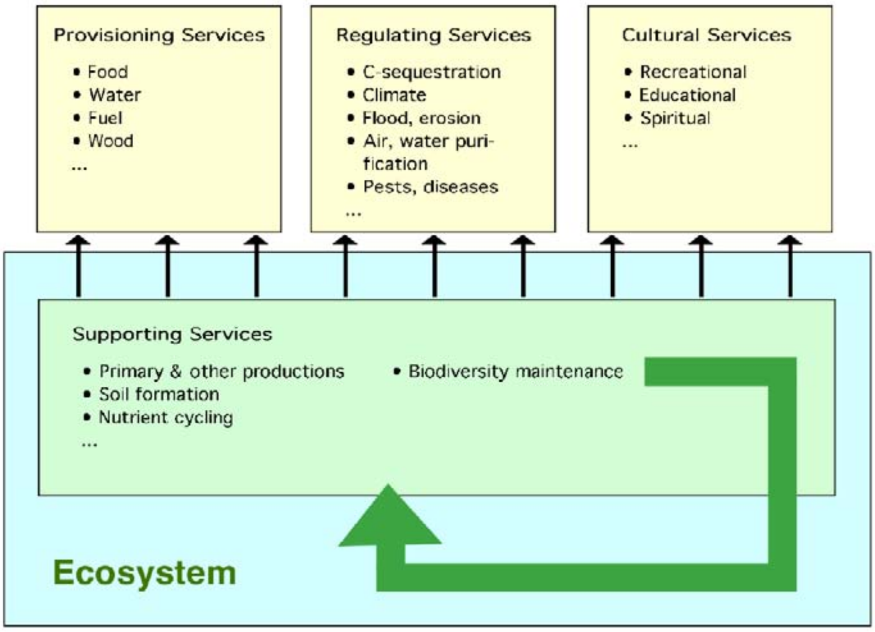

Fig. 4.1: *Ecosystem goods and services upon which human existence depends (this list is illustrative and not exhaustive). Note that biodiversity maintenance of ecosystems is seen here as a core supporting service, not only as a prerequisite of any ecosystem functioning (cf. Millennium Ecosystem Assessment: Hassan et al., 2005; Carpenter et al., 2005; Chopra et al., 2005; Capistrano et al., 2005; Millennium Ecosystem Assessment, 2005a; Reid et al., 2005).*

This chapter discusses many supporting, provisioning, and regulating services that are obtained from ecosystems: (i) primary production (as the basis for fuel wood, fibre, and fodder production) and (ii) primary or secondary production as the basis for other products (such as nuts, spices, aromatic plants, medicinal and cosmetic products, or games cf. Gitay *et al.*, 2001); (iii) services of paramount importance for human existence like a) climate and water regulation; b) water and air purification, c) carbon sequestration; d) disease, pest, and pathogen regulation.

4.1.3 Key issues

Ecosystems are expected to tolerate some level of future climate change and in some form or another will continue to persist (e.g. Kirschbaum and Fischlin, 1996; Gitay *et al.*, 2001).A key uncertainty, however, is whether the resilience (see glossary and e.g. Folke *et al.*, 2004) that ecosystems have developed during past environmental change (e.g. Harrison and Prentice, 2003) will be sufficient to tolerate rapid climatic changes in the future (e.g. Jump and Penuelas, 2005). Ecosystems are, moreover, increasingly subject to human induced pressures, such as extractive use of goods, and increasing fragmentation and degradation of natural habitats (e.g. Bush *et al.*, 2004). Climate change will exacerbate these human-induced pressures and this will tend to reduce taxonomic diversity. Furthermore, it is thought that passing critical thresholds may trigger non-linear responses that could lead to novel critical states that are poorly understood. Projected future climate change and other human-induced pressures are unprecedented compared with the past few millennia (WG I, chapter 2, and e.g. Petit *et al.*, 1999).

The timing of such effects is also important. Many ecosystems may take several centuries or even millennia (where soil formation is involved) to reach a quasi-equilibrium with a changed climate (e.g. Lischke *et al.*, 2002; Harrison and Prentice, 2003). Thus transient responses and the functioning of ecosystems under continuously changing conditions need to be understood to anticipate critical effects and the possible risk of coincident occurrence of effects that would otherwise be tolerable, i.e. if they happened at different times.

A further key issue is whether such transformations include species extinctions, since these represent irreversible change. This is crucial since many studies postulate a link between diversity and ecosystem functioning and changes in ecosystem services. Three effects seem possible (Millennium Ecosystem Assessment, 2005b p43-46): First, the loss of ecologically equivalent or redundant species decreases resilience. Secondly, loss of key predators or mutualists such as pollinators, or other keystone species alters ecosystem functioning. Thirdly, the loss of species that are ecological complements reduces overall performance in terms of provided goods and services.

4.1.4 Conclusions from the IPCC Third Assessment Report (TAR)

The TAR chapter on ecosystems (Gitay *et al.*, 2001) compiled a substantial set of observations on changed distribution ranges, which concur with theoretically expected responses and considered the role of other pressures apart from climate change. It presented losses of biomass over significant areas due to fragmentation, non-sustainable land use and desertification, and threats to biodiversity with 25% of mammals and 12% of birds being at significant risk of global extinction due to anthropogenic climate change. In spite of previously held views that aquatic ecosystems are buffered against warming, it was found that in many northern hemisphere lakes and rivers ice cover broke up earlier and froze later. The TAR also questioned the previously expected productivity increases due to CO_2 fertilization effects, and demonstrated that tundra and some peat lands have turned from a net carbon sink to a source of up to 0.7 Pg C yr^{-1}. This chapter is based on new findings since the TAR.

4.2 Current sensitivities

4.2.1 Insights from past climates

The atmospheric conditions of today are atypical for at least the past 750,000 years (Augustin *et al.*, 2004), and are imposed on a 100 ppmv CO_2 increase and a global warming of about 6ºC since the

LGM only 18,000 to 21,000 years ago. Ecosystems have not only responded to strong past climatic changes such as this relatively recent warming, but they also respond to ongoing climatic change (chapter 1, Moberg *et al.*, 2005). Ecosystems of the distant past which existed under conditions of warmer climates similar to the predicted levels of global warming were essentially different from the modern ecosystems both at the regional, zonal, and local levels (e.g. Velichko *et al.*, 2002), and in terms of species and life form composition. For example, grassland ecosystems became a dominant feature of the planet only about 8 million years ago (de Menocal, 2004). Furthermore, modern biota have evolved under relatively cool low CO_2 conditions for most of the Pleistocene, which may predispose them to negative effects of excessive anthropogenic warming (e.g. Alverson *et al.*, 2001).

Much evidence demonstrates that past climate changes have impacted the earth's biomes repeatedly and significantly over the course of geological history, with biomes that approximate those currently present arising after the Cretaceous age (Beerling and Woodward, 2001). Dropping atmospheric CO_2 concentrations and the establishment of seasonal climates resulted in the establishment of a modern assemblage of terrestrial biomes and their associated fauna by the Pleistocene (de Menocal, 2004). Pleistocene climate oscillations between cool glacial and warm interglacial conditions (the latter the predominant state for this era, Augustin *et al.*, 2004), appear to have caused substantial spatial shifts in major biomes, with northern Hemisphere glaciation causing repeated suppression and even elimination of biota at high latitudes. Fewer extremes may have led to lower levels of impact in southern Hemisphere ecosystems, and thus a greater accumulation of diversity (Jansson, 2003). The principal response to these changes appears to have been geographic shifts in species ranges, usually idiosyncratic and individualistic, such that current communities and species assemblages may not have existed in the past (Graham and Grimm, 1990). However, adaptive responses through selection has resulted in some level of species variation due to past climate change (Davis and Shaw, 2001).

4.2.2 Climatic variability and extremes

Earlier IPCC reports described several ecosystems to be resilient to warming up to 1° C (e.g. Kirschbaum and Fischlin, 1996), but recent studies have resulted in a new, more differentiated view of the sensitivity of ecosystems (e.g. Walther *et al.*, 2002) that includes understanding of the role of climatic variability and extremes. The links between climate variability and natural ecosystems has improved following progress in the understanding of the behaviour of decadal-scale climatic oscillations and their impacts that include ENSO (El Niño/Southern Oscillation) and the NAO (North Atlantic Oscillation). These low-frequency phenomena determine indirectly the response of vegetation, notably through the shifts in major controls (temperature, precipitation, snow cover). For example, the European Alps experience changes in regional climates that can be attributed in part to the shifting behaviour of the NAO (Hurrell and van Loon, 1997; Serreze *et al.*, 1997; Wanner *et al.*, 1997; Beniston and Jungo, 2002) such as the lack of snow in the late 1980s and early 1990s (Beniston, 2003). Reversals of precipitation regimes in the Pacific region and beyond during ENSO events can disrupt vegetation through drought, heat stress, spread of parasites and disease, and enhanced occurrence of fire (e.g., Diaz and Markgraf, 1992). Sea temperature increases associated with ENSO events have been implicated in reproductive failure in seabirds (Wingfield *et al.*, 1999), reduced survival and reduced size in iguanas (Wikelski and Thom, 2000), and major shifts in island food webs (Stapp *et al.*, 1999).

Many significant impacts of climatic change may emerge through shifts in the intensity and the frequency of extreme weather events. Extreme events can cause mass mortality of individuals and contribute significantly to determining which species occur in ecosystems (Parmesan *et al.*, 2000). Drought in particular plays an important role in forest dynamics, and has been responsible for pulses of tree mortality in the Argentinian Andes (Villalba and Veblen, 1997) and in the eastern Mediterranean (Körner *et al.*, 2005b). In the Canadian Rockies, times of extreme cold have been identified as a cause of tree death, with a sustained period of cold summers in 1696–1701 apparently being responsible for extensive tree mortality (Luckman, 1994). Conversely, in continental mid- and high-latitude regions, wind, snow and frost are the main causes of forest damage. Heat waves such as the recent 2003 event in Europe (Beniston, 2004; Schär *et al.*, 2004 see also Box 4.1) have both short-term and long-term implications for vegetation, particularly if accompanied by drought conditions. The long-term response of vegetation to a particular climatic extreme varies according to the species. Some plants may in the year following a major desiccation or heat-stress event enhance their biological productivity in order to ensure reproduction and perpetuation in the face of adversity. Hurricanes can lead to direct mortality, and their aftermath may cause declines due to loss of resources required for foraging and breeding (Wiley and Wunderle, 1994). The December 1999 "storm-of-the-century" that affected western and central Europe destroyed trees at a rate of up to 10 times that of the annual felling rate in parts of France and Switzerland (Anonymous, 2001). Loss of habitat due to hurricanes can also lead to greater conflict with humans. For example, fruit bats (*Pteropus spp*.) have declined recently on American Samoa due to a combination of direct mortality events and increased hunting success by local peoples in the altered habitats (Craig *et al.*, 1994).

Box 4.1: Ecological Impacts by the European heat wave 2003

Anomalous hot and dry conditions affected Europe between June and mid-August of 2003 (Schär *et al.*, 2004; Luterbacher *et al.*, 2004). The risk of summers as warm as 2003 may increase by two orders of magnitude in the next 40 years (Stott *et al.*, 2004) and similar heat wave conditions are likely to increase in frequency (Meehl and Tebaldi, 2004) becoming the norm by 2080 in an SRES A2 world (Schär *et al.*, 2004; Beniston, 2004). Future projections for southern Europe suggest significant species richness losses even under mean climate change conditions (Thuiller *et al.*, 2005), let alone for climate extremes. The major impact of the 2003 heat wave on vegetation and ecosystems appears to have been through drought stress (Gobron et al., 2005), causing reductions of up to 30% in GPP, resulting in a net carbon source of 0.5 Pg C yr^{-1} (Ciais *et al.*, 2005). Some vegetation types may have recovered by 2004 from the effects of drought (Gobron *et al.*, 2005), which conforms with the findings of modelling studies (Fischlin *et al.*, 2007), but enhanced crown damage of dominant forest trees in 2004 suggests complex delayed impacts (Fischer, 2005). This suggests a certain resilience in some ecosystems, but only if such events remain rare (Gobron *et al.*, 2005).

In addition, a record-breaking incidence of spatially extensive wildfires was observed in some countries (Barbosa et al., 2003). Although the number of fires was not exceptional in Spain, Italy, Greece, and France, in Portugal in particular forest fires were much more extensive than have been recorded before, due to particular conditions of drought, high temperature and reduced humidity. These burned over more than 450,000 ha, twice the previous extreme (1998), and four times the 1980-2004 average (Trigo et al., 2005). By the third week of August, fires had burned in excess of 5.6% of the total forest surface of the country, with an economical impact exceeding 1 billion Euro (De Bono et al., 2004). Furthermore, by promoting the regrowth of highly flammable, shrubby vegetation that is more frequently burned than other land-cover types (Nunes et al., 2005), and due to the tendency of burned woodlands to reburn at shorter intervals (Vazquez and Moreno, 2001; Salvador et al., 2005), this may have produced a long-term impact. In addition, the conversion of vegetation structure on a large enough scale may even cause an accelerated change in climate (Cox et al., 2000). Emissions of other compounds such as carbonyl sulphide by wildfires feed back on regional climates through their effects in the stratosphere (Notholt et al., 2003), and have even been shown to disrupt cloud formation processes (Koren et al., 2004).

4.2.3 Disturbance and other drivers

Ecosystems are sensitive not only to the direct effects of climate, but also to multiple interacting pressures such as land use change, fire, pollution and invasive species (global change drivers), which may also be climate dependent (Reid *et al.*, 2005; Sala *et al.*, 2000). In the recent past many anthropogenic pressures exerted on ecosystems have intensified (Gitay *et al.*, 2001). This includes unsustainable resource utilization, pollution (e.g. Lelieveld *et al.*, 2002), alterations to nutrient cycles (e.g. Vitousek *et al.*, 1997b), land-use change (Lepers *et al.*, 2005), and redistribution of biota through greater human mobility (e.g. Mack *et al.*, 2000). The explicit inclusion of non-climate drivers in analyses of climate change could lead to unexpected outcomes (Hansen *et al.*, 2001; Duraiappah *et al.*, 2005). Consequently, many impact studies of climate change may be conservative estimates (e.g. studies that assume species migration across fragmented landscapes Pearson and Dawson, 2005).

Land use change is recognized as a primary global change driver (Hansen *et al.*, 2001; Guo, 2000; Lambin *et al.*, 2003; Korner, 2003; Lepers *et al.*, 2005; Jenkins, 2003; Carpenter *et al.*, 2005; Sala *et al.*, 2000). This may be replacement of one land cover type by another, e.g. forest to cultivated land, as well as subtle changes of management practices within a given cover, e.g. intensification of agricultural land, both of which have transformed ~40% of the terrestrial surface (reviewed by Foley *et al.*, 2005). Several studies suggest that land use change has been and will continue to be a more important driver for ecosystems than climate change (Slaymaker, 2001; Sala *et al.*, 2000; Jenkins, 2003; Carpenter *et al.*, 2005; Heywood and Watson, 1995; Gaston *et al.*, 2003). However, the interactions between climate, land use and biodiversity are problematic for any consideration of these factors in isolation (Hansen *et al.*, 2001; Lambin *et al.*, 2003; Carpenter *et al.*, 2005).

Fire influences community structure by favouring species that tolerate fire or even enhance fire spread, resulting in evolved flammability in species and communities (Bond and Keeley, 2005), and vegetation types that are far from maximum biomass predicted by regional climate (Bond *et al.*, 2005). Thus geographic shifts in key species or fire weather may cause fundamental community shifts (Brooks *et al.*, 2004). Fire-prone vegetation types cover a total of 40% of the world's land surface (Chapin *et al.*, 2002), and are common in tropical and subtropical regions often in the southern Hemisphere (Bond *et al.*, 2005), with the exception of the boreal forest (Kasischke *et al.*, 1995; Peng and Apps, 1999). Changes in fire regime driven at least partly by 20th century climate change (Gillett *et al.*, 2004), in conjunction with people (Wotton *et al.*, 2003), appear to be changing vegetation structure and composition, such as shifts from Picea to Pinus-dominated communities and 75-95% reductions in tree densities (Lavoie and Sirois, 1998). Drought facilitated the spread of human-caused fire in tropical regions during the 97/98 El Nino (Randerson *et al.*, 2005), affecting atmospheric trace gas concentrations (CO, CH_4, H_2) at hemispheric scales (Kasischke *et al.*, 2005; Langenfelds *et al.*, 2002; Novelli *et al.*, 2003). Tropical forest fires are becoming more common (Cochrane, 2003). In the Amazon, anthropogenic fires have strong negative effects on vegetation (Cochrane and Laurance, 2002; Haugaasen *et al.*, 2003), and may even alter regional rainfall patterns (Andreae *et al.*, 2004). Significant progress on globally applicable models of fire represented in DGVMs has been made since TAR (Thonicke *et al.*, 2001; Fosberg *et al.*, 1999) and suggests increases in fire frequencies (e.g. Stocks *et al.*, 1998) with associated impacts (4.4.1, 4.4.5). The implications of the importance of fire globally are manifold (Bond *et al.*, 2005). Firstly, fire suppression strategies are often limited in effect (Schoennagel *et al.*, 2004; Keeley, 2002; Van Wilgen *et al.*, 2004). Therefore management needs to incorporate adaptation as well as protection options, as enhancement of vegetation flammability by more prevalent fire weather and resulting big wildfires threatens human settlements, infrastructure, and livelihoods (e.g. Allen Consulting Group, 2005). Secondly, in some ecosystems, including islands, introduced fires have transformed forests into more flammable shrublands and grasslands (Ogden *et al.*, 1998). Thirdly, the drivers of flammability, such as ecosystem productivity, fuel accumulation, and environmental fire risk conditions, are all influenced by climate change (Williams *et al.*, 2001).

Invasive alien species (IAS) are a major threat to biodiversity (Sala *et al.*, 2000; Vitousek *et al.*, 1997a). Causes of biological invasions are multiple and complex (Dukes and Mooney, 1999), yet some simplifying approaches have been developed (Crawley, 1989; Chytry *et al.*, 2005; Deutschewitz *et al.*, 2003; Facon *et al.*, 2006). Complex interactions may have unexpected outcomes; for example, after invasive rabbits were eradicated from the Kerguelen Islands, recent drying slowed native vegetation recovery, allowing exotic vegetation to become dominant (Chapuis *et al.*, 2004). Change in biotic and/or abiotic disturbance regime is a primary driver of IAS (Le Maitre *et al.*, 2004), and communities become generally more susceptible to invasion following extreme events (Smith and Knapp, 1999). Human-disturbed habitats in Britain have been shown to be rich in alien species (Crawley *et al.*, 1996). IAS can also introduce disturbance regimes by enhancing vegetation flammability (Brooks *et al.*, 2004). Overall, ongoing shifts in human mediated disturbances, insect pests, IAS and fire regimes can be seen to interact to alter regional vegetation structure, diversity and function (e.g. Timoney, 2003).

4.3 Assumptions about future trends

Climate models remain the tool of choice for constructing future climate scenarios (WG I chapter 8) used to force ecosystem or species-based impacts models. Simple global or regional temperature and precipitation scenarios are usually sufficient to design experimental manipulations to test ecosystem and species impacts and sensitivities empirically, though these more recently include also manipulations of rainfall variability.

Confidence in future climate projections has increased recently (WG I Chapter 8) and many global or regional scenarios are now available to quantify future impacts (Nakicenovic *et al.*, 2000; Christensen *et al.*, 2002 WG I chapter 10 and 11, Box 4.2). Ecosystem and species-based models function typically at scales much finer than are resolved or reliably represented in global climate models. Requisite downscaling techniques of various types (dynamic, empirical) have matured and are increasingly applied to provide the needed spatio-temporal detail (IPCC-TGCIA, 1999; Mearns *et al.*, 2003; Wilby *et al.*, 2004). Physically consistent bioclimatic scenarios can now be derived for almost any region, including developing countries and complex, mountainous terrain (Box 4.2 Gyalistras and Fischlin, 1999). However, since water balance and weather extremes are key to many ecosystem impacts, and since confidence in scenarios for precipitation is significantly lower than for temperature and climate extremes, despite recent improvements (WG I Chapter 8), there remain a significant range and major uncertainties in the impact projections presented in this chapter.

Box 4.2: Generating bioclimatic scenarios to quantify ecosystem impacts

To assess future impacts on ecosystems we need scenarios based on projections of future climate. Recent advances have enabled to generate such scenarios not only for the entire globe but also for particular regions of interest. For an IPCC SRES A2 scenario (Nakicenovic *et al.*, 2000) the EU-PRUDENCE study (Christensen *et al.*, 2002) projected 4°C warming for much of Europe by 2071-2100. This is expected to be accompanied by more short-duration but intense convective rainfall events (e.g. 30% frequency increase for a 2°C warming Frei *et al.*, 1998), plus a general northward migration of climatic zones, leading in some southern Mediterranean areas to a warming that exceeds 8-10°C with concomitant droughts. A similar tendency of simultaneous increases in the frequencies of both drought and intense precipitation events has also been reported for other mid-latitudes, e.g. for North America (e.g., Houghton *et al.*, 2001; Trenberth, 1999). Such changes can have significant repercussions for hydrology and ecosystems, with extreme temperatures likely to exert stronger controls on evaporation or desiccation, heat and water stress on plants than mean temperatures (Fuhrer *et al.*, 2007). In complex terrain such as the Alps, scenario generation faces particular challenges, since ecosystem processes depend on steep environmental gradients and operate on fine spatial scales (Gyalistras *et al.*, 1994; Fischlin and Gyalistras, 1997), e.g. beta diversity tends to be greater than in flat areas (cf. Körner, 2000). Systematic climate model errors may exceed the climate change signal (Gyalistras *et al.*, 1994; Beniston, 2003; Antic *et al.*, 2006). Nevertheless, nested, high-resolution RCM simulations (5-km and 1-km scales) simulate in a physically consistent manner processes such as surface runoff, infiltration, and evaporation (e.g., Arnell, 1999; Bergstrom *et al.*, 2001), extreme precipitation events (Frei *et al.*, 1998), and damaging wind storms (Goyette *et al.*, 2003). Preliminary results from simulations of extreme winter storms (e.g. 1999 Lothar storm Wernli *et al.*, 2002; Goyette *et al.*, 2003) indicate a future increased frequency of strong winds originating in the Atlantic at the expense of Föhn-type storms related to southerly flow across the Alps. Sensitivity of forests to wind-stress increases markedly if return time of wind-storms decreases (Thurig *et al.*, 2005a; Fuhrer *et al.*, 2007) thereby hindering recovery of forest ecosystems in particular if also subject to pollution from nitrogen deposition and acidification (Braun *et al.*, 2003).

Climate change is one of several interacting forces of global change, but these are often not well integrated in impact studies. For example, despite the recognized importance of land use change, it is rarely included in current global climate models (Hansen *et al.*, 2001; Zebisch *et al.*, 2004; Holman *et al.*, 2005b; Levy *et al.*, 2004; Pielke Sr, 2005; Feddema *et al.*, 2005). This is likely due to an insufficient understanding of the underlying causes, trends and outcomes of land use and land cover change at the global scale (Hansen *et al.*, 2001; Lambin *et al.*, 2001; Lambin *et al.*, 2003). However, much progress has been made in this area, both in a better understanding of underlying processes and development of useful model projections (Lambin *et al.*, 2003). Several studies incorporating land use change have been undertaken at local and regional scales (section 4.4.10). Explicit inclusion of land use change in climate change analyses may reveal unexpected outcomes, in particular for biodiversity (Hansen *et al.*, 2001). Consequently, many impact studies of climate change that ignore land-use and other global change trends may represent conservative estimates of projected ecosystem responses.

4.4 Key future impacts and vulnerabilities

To project impacts on ecosystems to projected climatic changes, many assumptions can and are being made. They give raise to basically three approaches: (i) correlative, (ii) mechanistic, and (iii) anolog approaches. For the correlative (i) and mechanistic (ii) approach, studies and insights from the presence form the basis to assume that the very same mechanisms will continue to exist in the future and that the same set of causes will be responsible for the ecosystem's response under future climatic conditions. Both approaches often deploy models, which are either based on correlative, or causal relationships between aspects of ecosystems structure and function, or a mixture of both. They capture the assumptions and the current understanding of the driving mechanisms and are used to project observed sensitivities and trends quantitatively into the future; Evidence from past climate changes (iii) is used to extrapolate for analogous future situations. All three approaches have their merits and drawbacks.

4.4.1 Biogeochemical cycles and biotic feedback

The cycling of chemical elements and compounds underpins the function of the biosphere and links ecosystems and climate by regulating chemical concentrations in soil, biota, atmosphere and ocean. Substantial progress has been made since TAR in understanding the interactive responses of ecosystems and the climate system, as determined by plant physiological responses, interactions with soil, and their scaled-up effects on regional and global biogeochemical cycles (Gedney *et al.*, 2006;

Buchmann, 2002). The most advanced tools to achieve this scaling-up to global scale are Dynamic Global Vegetation Models (DGVMs), that simulate time-dependent changes in vegetation distribution and properties, and allow mapping of changes in ecosystem function and services (Metzger *et al.*, 2006; Schroter *et al.*, 2005). Reliability of results has improved in relation to previous generations of models but several aspects remain incompletely tested. Yet, validation is ongoing (e.g. Woodward and Lomas, 2004b; Prentice *et al.*, 2006), and testing at hierarchical levels from leaf to biome and over relevant time scales have shown encouraging matches with observations (Lucht *et al.*, 2002; Bachelet *et al.*, 2003; Harrison and Prentice, 2003; Kohler *et al.*, 2005; Gerten *et al.*, 2004; Joos and Prentice, 2004; Peylin *et al.*, 2005).

Key vulnerabilities as from TAR: Based on methods that predate and developed into DGVMs (equilibrium biogeography models or global biogeochemical models Neilson *et al.*, 1998), the world's terrestrial ecosystems will likely continue to sequester carbon for a number of decades and possibly throughout the 21st century, with an initially 'greening' world due to longer growing seasons, more precipitation, and CO_2 fertilization benefits. Substantial structural changes in biomes could occur towards 2100 with ecosystem shifts toward higher latitudes and altitudes as CO_2-fertilization benefits saturate and increasing temperature effects on respiration and transpiration could reverse initial carbon sequestration gains resulting in net global ecosystem carbon losses relative to today (e.g. Cramer *et al.*, 2001). Dieback of much of the Amazon rainforest, due to desiccation, was an identified major vulnerability, but with a high degree of uncertainty. TAR concluded the net global terrestrial carbon exchange would be between -6.7 $PgCyr^{-1}$ (uptake) and +0.4 $PgCyr^{-1}$ (loss), and that anthropogenic CO_2 emissions would remain the dominant determinant of atmospheric CO_2 concentration during the 21st century. Key ecosystem forecasting needs identified in TAR were for spatially and temporally dynamic models containing all processes that produce inertia and lags in ecosystem responses, allowing reproduction of non-linear behaviour if conditions reach critical levels that feedback to and interact with climate evolution.

Impacts: Scaled-up effects of direct atmospheric CO_2 enrichment on plant and ecosystem biomass accumulation (CO_2 fertilization) are largely responsible for the enhanced NPP in current global models (Leemans *et al.*, 2002). However, based on improved experiments, magnitudes of this effect are being revised downwards. Three constraints increasingly acknowledged are element stoichiometry (nutrients), forest tree dynamics, and secondary effects of CO_2 on water relations and biodiversity. Trends in empirical data suggest caution when estimating future carbon sequestration potentials of the biosphere as a contribution to mitigating climate change, in particular as these benefits may be smaller than counteracting impacts of land use change. Persistent grassland responses to elevated CO_2, which range from 0 to 40 % biomass gain per season, mainly reflect CO_2-induced water savings induced by scaled-up impacts of reduced stomatal conductance (Morgan *et al.*, 2004; Gerten *et al.*, 2005), and thus rely on current moisture regimes and lack atmospheric feedback. The only replicated test of multiple CO_2 x climate/environment interactions (water, temperature, nutrient supply) yielded no overall CO_2 biomass signal (Shaw *et al.*, 2002) highlighting significant influence of co-limiting environmental variables. Current best estimates for stimulation of agricultural production have also been reduced to 7-12 % for CO_2 doubling of pre-industrial CO_2 concentrations (Kimball *et al.*, 2003; Kimball *et al.*, 2002).

Similar trends are emerging for forests, although the interpretation is complicated by time lags in biomass response to the artefactual step-change when initiating CO_2 treatments, requiring long observation periods before a new steady state is reached. All three tall forest test systems, loblolly pine plantation (Oren *et al.*, 2001; Schafer *et al.*, 2003), sweet gum plantation (Norby *et al.*, 2002; Norby and Luo, 2004), and mixed deciduous forest (Körner *et al.*, 2005a) exhibit significant initial biomass stimulation, rapidly diminishing with time except for one of the four pairs of test plots (treatment vs. control) in the joint Duke pine experiments (Schafer *et al.*, 2003). Scrub oak in Florida shows similar diminishing responses as treatment proceeds (Hungate *et al.*, 2006), even though this is a post-fire regenerating system. All other test systems with trees are vigorously expanding and too young to permit analogies for steady state forest biomass responses. However, it has been suggested that greatest CO_2 fertilization impacts may be seen in such systems (Bond and Midgley, 2000; Bond *et al.*, 2003), especially where nutrients and water are less limiting and trees require carbon reserves to re-establish in fire-prone grasslands (see section 4.2.2). However, such gains in early life stage growth rate may not translate into greater landscape carbon sequestration which is largely determined by recalcitrant carbon pools in soils and long-lived biomass. For tropical forests, the planet's single largest biomass carbon reservoir, post-industrial atmospheric CO_2 enrichment seems to have enhanced growth dynamics (Phillips *et al.*, 2002; Wright *et al.*, 2004). A more dynamic forest is likely to store less rather than more carbon in future (Korner, 2004), especially given the exceptional CO_2 responsiveness of tropical lianas that may increase tree mortalities and population turnover.

Best estimates of CO_2-induced water savings in forests due to reduced stomatal aperture range between 5 and 15 % (Wullschleger and Norby, 2001; Cech *et al.*, 2003) for humid soils and good weather conditions, diminishing with drying soils. Desert shrub systems profit from CO_2 enrichment only during exceptional wet periods and not in dry periods (Nowak *et al.*, 2004), contrasting with earlier expectations. Evapotranspiration rate data for temperate zone ecosystems under future CO_2 scenarios suggests that these may be reduced by less than 10%, across all weather conditions. Water savings through elevated CO_2 have very little effect on trees during drought, because benefits disappear after a few days when the nutrient cycle in the top soil becomes interrupted, and when the initial water savings are used up (Leuzinger *et al.*, 2005). Repeated drought associated with high temperatures as experienced by Europe in 2003 may reduce landscape-wide carbon stocks (Ciais *et al.*, 2005). Experimental data for intact ecosystems suggest far smaller hydrological effects than those derived from gas exchange theory (Gedney *et al.*, 2006). These effects should become further diminished as atmospheric feedback resulting from reduced evaporation comes into play.

Soil nitrogen availability may be key to predict future carbon sequestration by terrestrial ecosystems (Reich *et al.*, 2006), especially in the light of global N-deposition trends (Matson *et al.*, 2002). Loblolly pine forest (Lichter *et al.*, 2005) and grassland experiments (Van Kessel *et al.*, 2000) have significantly reduced hopes for CO_2-fertilization driven carbon accumulation in soils, probably because carbon sequestration to humus is more nutrient demanding (in particular of nitrogen), than is e.g. wood formation (Hungate *et al.*, 2006). Carbon accretion in soil would therefore exert negative feedback on plant growth by immobilizing soil nutrients and as more multi-year study results become available, acclimation effects reducing the CO_2-fertilization indicate a faster diminishing of the biospheric sink than previously assumed (Fig. 4.2, Reich *et al.*, 2006) and used in model projections (Fig. 4.2, e.g. Scholze *et al.*, 2007). Build-up of seasonally transitory soil C-pools such as in fine roots has been found to increase net primary production, but the generality of such enhanced C-fluxes and what fraction might add to soil carbon stocks remain unresolved (Norby *et al.*, 2004). Soil warming has raised fears of carbon release, but whether this alone will diminish soil humus pools is an open question. Because soil respiration is largely driven by net primary production, there is no obvious reason for a decoupling of respiration from carbon fixation in hot climates (e.g. Eliasson *et al.*, 2005), though in regions with thawing permafrost and lengthening of an otherwise cool season (reduced periods of anaerobic soil conditions) a decay of previously accumulated soil carbon stocks could release large amounts of carbon to the atmosphere. Accordingly, recent observations show widespread carbon losses from soils (Bellamy *et al.*, 2005; Schulze and Freibauer, 2005), though by contrast, soil respiration rate under *in situ* boreal forest trials increased due to warming but rapidly slowed once labile soil-C had equilibrated under warmer conditions (Eliasson *et al.*, 2005).

Changing fire regimes (see 4.2.2) are of significant concern for terrestrial carbon balance. Simulation of fire has improved substantially (see 4.4.2), and some models simulate individual fire event impacts on ecosystems (Lenihan *et al.*, 1998; Thonicke *et al.*, 2001). Yet, individual fire-generated age-classes are not explicitly simulated (Smith *et al.*, 2001; Moorcroft *et al.*, 2001) thus projecting CO_2 effects inconsistently with implied age-class structure. Small-scale fluxes from heterogeneous vegetation can be summed for coupling to an atmospheric model (Woodward and Lomas, 2001), for future development. DGVMs also assume rapid migration of species that comprise the generic "plant functional types" that are modelled to shift in geographic distribution (e.g. Leemans and Eickhout, 2004), thus modelled carbon sequestration gains from northward migration of the boreal forest (Neilson *et al.*, 2005) are likely to be overoptimistic (see 4.4.5).

Ecosystem changes associated with land use and land cover change (see 4.2.2) are complex, involving a number of feedbacks (Lepers *et al.*, 2005; Reid *et al.*, 2005). For example, conversion of natural vegetation to agricultural land drives climate change by altering regional albedo and latent heat flux, causing additional summer warming in key regions in boreal and Amazon region, and winter cooling in the Asian boreal zone (Feddema *et al.*, 2005), by releasing CO_2 via losses of biomass and soil carbon (Levy *et al.*, 2004; Gitz and Ciais, 2003; Canadell *et al.*, 2004), and through a 'land use amplifier effect' (Gitz and Ciais, 2003). In contrast, reforestation, and other land use or land management changes such as modifications to agricultural practices can work to mitigate climate change through carbon sequestration (Jones and Donnelly, 2004; Lal, 2004; Lal, 2003; de Koning *et al.*, 2005; Wang *et al.*, 2004a; King *et al.*, 2004a), but are limited by decades-long time-lags to replace old-growth forests.

Ecosystems are likely to respond to increasing external forcing in a nonlinear manner. Most initial ecosystem responses appear to dampen change (Aber *et al.*, 2001), but amplify it if thresholds in magnitude or rate of change are crossed. Transitions between states may be triggered or the ecosystem may even collapse (Rietkerk *et al.*, 2004; Scheffer *et al.*, 2001; Schroder *et al.*, 2005).

The sequestration and cycling of carbon in terrestrial ecosystems is a key concern, given the above drivers and concerns about threshold impacts. Recent work with DGVM approaches has begun to elucidate the likelihood of occurrence of important thresholds, and positive feedback to the atmosphere through carbon release from ecosystems. Global estimates (IS92a, HACM2-SUL Cramer *et al.*, 2001) suggest a reduced global sink relative to that expected under CO_2 fertilization alone, both in 2000 (0.6± 3.0 PgCy±1) and 2100 (0.3±6.6 PgCy±1) as a result of climate change impacts on Net Ecosphere Productivity (NEP) of tropical and southern hemisphere ecosystems; the rate of increase of NEP slows around 2030 as CO_2 fertilization itself saturates, and in four of six models show further, climate-induced NEP declines, due to increased heterotrophic respiration and declining tropical NPP post-2050. These trends could develop for a century beyond 2100, even with stabilized atmospheric CO_2 concentration and instantaneously stabilized climate. 20th century climate, nitrogen deposition and CO_2 change alone may have increased carbon sequestration by up to 2500 gCm^{-2} in tropical and boreal forest regions, but the terrestrial biosphere could become a net CO_2 source after CO_2 fertilization saturates post-2020 (HadCM3 with additional CO2 and warming feedback from global vegetation response, Woodward and Lomas, 2004b). More recent modelling based on projected deforestation and climate change (IS92a, CGCM1, CSIRO, ECHAM, HadCM3) in the tropics alone suggest an additional release of 101 to 367 Pg C, adding between 29 and 129 ppm to global atmospheric CO_2 by 2100, with much of this, on balance, sourced from deforestation rather than climate change (Cramer *et al.*, 2004). Climate scenario uncertainty provides a substantial variance in global terrestrial C balance by 2100, even under a single CO_2 emission scenario (IS92a, reaching 703 ppm atmospheric CO2 concentration by 2100, excluding vegetation feedback), with five GCMs driving DGVM estimates of global terrestrial C-sequestration of between -106 to +201 PgC (Schaphoff *et al.*, 2006), though in four out of five, the sink had begun decreasing from a peak well before 2060. A risk assessment for terrestrial biomes and biogeochemical cycling shows that a terrestrial carbon source is predicted in almost half of 52 GCM x emissions scenario combinations (Scholze *et al.*, 2007), and that wildfire frequency increases dramatically even for 2100 warming of <2ºC.

Here we show model results for the most recent version of the DGVM LPJ (Schaphoff *et al.*, 2006) of shifts in biome structure and the terrestrial carbon sink under more recent IPCC emission scenarios SRES A2 and B1 (Nakicenovic *et al.*, 2000). This supports projections of diminishing terrestrial C-sequestration as soon as 2030 (Fig. 4.2), far earlier than suggested in TAR (WG I, Figure 3.10), and substantial shifts in biome structure (Fig. 4.4).

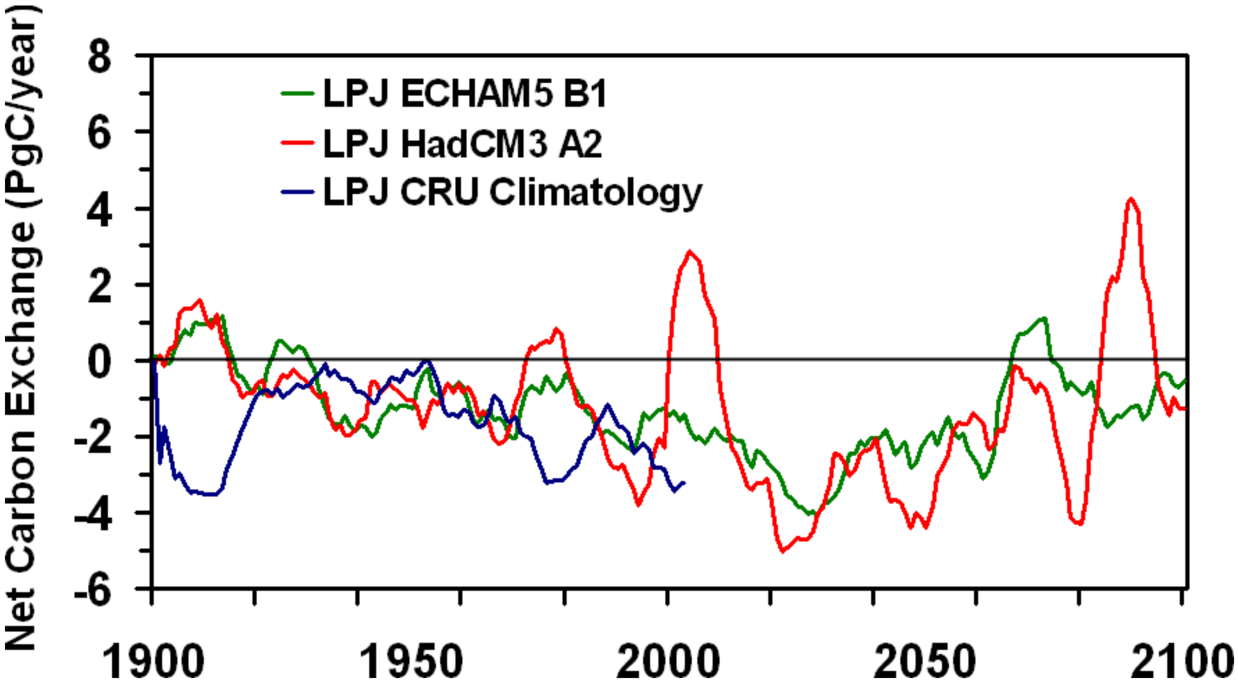

Fig. 4.2: *Net carbon exchange of all terrestrial ecosystems as simulated by the dynamic global vegetation model (DGVM) LPJ (Gerten et al., 2004; Sitch et al., 2005 - negative values mean a carbon sink, positive values carbon losses to the atmosphere). Past century data are based on observations and climate model data were normalised to be in accord with these observations for the period 1961-1990 data (CRU-PIK). Transient future projections are for the IPCC SRES A2 and B1 emission scenarios (Nakicenovic et al., 2000) forcing the climate models HadCM3 and ECHAM5, respectively, (cf. Schaphoff et al., 2006). In contrast to previous global projections (TAR WG I, Figure 3.10) the world's ecosystems tend to become a carbon source earlier (here sink peak ~2030) and more consistently, corroborating other projections of increased forcing from biogenic terrestrial sources (e.g. Cox et al., 2000; White et al., 2000a; Cox et al., 2004; Schaphoff et al., 2006; Scholze et al., 2007 - see Fig. 4.4 for maps on underlying ecosystem changes and Table 4.3). Note, these projections assume an effective CO2 fertilization (cf. 4.4.1).*

Impact modeling (Fig. 4.2) and modeling that dynamically links the physical climate system and vegetation, using Ocean-Atmosphere-General Circulation Models (OAGCMs, e.g. Cox *et al.*, 2000) projects a terrestrial C source that will exacerbate both climate and further vegetation change to some degree (e.g. Sarmiento, 2000; Dufresne *et al.*, 2002; Canadell *et al.*, 2004). Impacts include the collapse of the Amazon forest (e.g. White *et al.*, 2000a; Cox *et al.*, 2004), and an overall C source from the tropics that exceeds the boreal C sink (Berthelot *et al.*, 2002), leading to an 11% (Cox *et al.*, 2000) to 40% (Dufresne *et al.*, 2002) higher atmospheric CO_2 concentration by 2100. Carbon and water cycling, at least, are also affected by shifting biogeographic zones (Gerten *et al.*, 2005) that will be lagged by migration constraints that are not yet incorporated in DGVM approaches (see also 4.4.5 and 4.4.6), leading to a potential overestimation of vegetation C-sequestration potential, especially for regions such as the boreal, that are projected to benefit from in-migration of woody vegetation, while biomes that experience dieback will do so with shorter time lags (Neilson *et al.*, 2005).

Interactions between ocean and atmosphere and land and oceans may also be critical for future evolution of climate. For example, dimethyl sulphide (DMS) is a significant source of cloud condensation nuclei and changes in air-sea fluxes caused by global warming at 2 × CO_2 can result in regional radiative impact, from –15% to 30% and impact regional climate (Bopp *et al.*, 2004; Bopp *et al.*, 2003). DMS produced by coccolithophores may be influenced by their sensitivity to high seawater CO_2 (Riebesell *et al.*, 2000). As the largest producer of calcite on the planet (Holligan *et al.*, 1993) reduced calcification may also influence the global carbon cycle (Raven *et al.*, 2005) and the albedo effect of the Earth (Tyrrell *et al.*, 1999). N_2O from marine origin contributes ~33% of total input to the atmosphere (Prather and Enhalt, 2001). Changes to the concentration and distribution of oxygen in the oceans, either through increased stratification of the surface waters (Sarmiento *et al.*, 1998) or through a decrease in the strength of thermohaline circulation (Houghton *et al.*, 2001), will impact the ocean nitrogen cycles, especially the processes of nitrification and denitrification which promote N_2O production. The extent to which the unanticipated and recently discovered methane release from plant foliage (Keppler *et al.*, 2006), can be scaled from individual leaf to biome level, is an ongoing debate.

4.4.2 Deserts

Characteristics: The largest terrestrial biome, comprising extra-polar regions with mean annual precipitation <250mm and unfavourable precipitation to potential evaporation ratio (Table 4.1 Nicholson, 2002; Warner, 2004; Reid *et al.*, 2005). Deserts are sparsely populated with rural human population densities of between 1 and 3 km^{-2}, and among the lowest GDP of all ecosystems (Reid *et al.*, 2005).

Goods and services: Food, including rangeland grazing and wild foods; Ecotourism; Cultural and sense of place; Genetic resources, especially of arid-adapted species (Hassan *et al.*, 2005). Biodiversity (especially winter-rainfall deserts e.g. Myers *et al.*, 2000). Air quality, atmosphere composition and climate regulation (Hassan *et al.*, 2005); Wind-blown dust and desert albedo influences regional rainfall and biogeochemistry of remote terrestrial and marine ecosystems (Lioubimtseva and Adams, 2004; Warner, 2004).

Key Vulnerabilities as from TAR: Deserts were grouped with semi-arid and dry sub-humid rangelands by TAR. Noted vulnerabilities (TAR p.239) included possible region-specific increases in productivity due to increases in rainfall and rising atmospheric CO_2, potentially offset by management and rising temperatures; some regions of desert expansion; extensive animal production threatened by rangeland over-utilization; secondary salinization in dry lands partly offset by elevated CO_2 and and associated increased biomass and soil organic matter in deserts (Poorter and Perez-Soba, 2001; Lioubimtseva and Adams, 2004); overall lack of infrastructure and investment in resource management.

Impacts: Despite substantial disagreement among GCM projections, future rainfall change in deserts seems likely to be season-specific, and inter-annual variation will increase. Mid-continent deserts could experience more severe, persistent droughts (Lioubimtseva and Adams, 2004; Schwinning and Sala, 2004). Combined with elevated CO_2, these changes are likely to favour desert shrub species and this may further increase evapo-transpiration (Bassirirad *et al.*, 1997; Smith *et al.*, 2000). Deserts may experience more episodic climate events in future (Smith *et al.*, 2000). Deserts of the southwest USA may shrink by up to 60% (Bachelet *et al.*, 2001; Hardy, 2003; Duraiappah *et al.*, 2005). Desert biodiversity will be vulnerable to climate change (Reid *et al.*, 2005): In the Chihuahuan desert habitats of about half the species could be eliminated (Lenihan *et al.*, 2003), while in the Succulent Karoo, doubled CO_2 climate scenarios lead to a median 19.2% endemic species extinction for a range of assumptions (Malcolm *et al.*, 2006). Daytime *in situ* warming experiments suggest high vulnerability of endemic succulent growth forms of the Succulent Karoo to high-end warming scenarios for 2100 (mean 5.5ºC above ambient), inducing appreciable mortality within only a few months (Musil *et al.*, 2005). Indeed, Namib desert tree aloes (*Aloe dichotoma*) show latitudinal trends in mortality, highest at the equatorward edges of their range, that suggest ongoing directional range contraction in response to increasingly unfavourable water balance (Foden *et al.*, 2007).

Desert species that depend on rainfall events to initiate breeding will be severely affected as will be the case for migratory birds although others suggest that resident bird communities may be more vulnerable (Dukes and Mooney, 1999; Myers *et al.*, 2000; Hardy, 2003). In South Africa, a wide-ranging bird species of the Nama-Karoo desert species, the Mountain Wheatear, was projected to lose 51% of its bioclimatic range by 2050 (HadCM3 A2 Simmons *et al.*, 2004). In contrast, desert reptile species could be favoured by warming as will be the case for amphibians (depending on rainfall scenarios Currie, 2001).

Extremely wet periods will result in high vulnerability to invasive alien species and subsequent fire outbreaks and this combined with land use disturbances will increase vulnerability to desertification (Dube and Pickup, 2001; Holmgren and Scheffer, 2001; Geist and Lambin, 2004; Lioubimtseva and Adams, 2004; Dukes and Mooney, 1999; Brooks *et al.*, 2004). Vulnerability to desertification will be enhanced due to existence of shallow soils with higher soluble salts and the slow recolonization of soil surfaces by different algae components (Evans and Belnap, 1999; Johansen, 2001; Billings *et al.*, 2003; Duraiappah *et al.*, 2005). Very low biomass (below 14% threshold limit) will make Kalahari desert dune system susceptible to aeolian erosion (Thomas and Leason, 2005), and with regional warming of between 2.5 to 3.5^{0}C most dune fields could be reactivated by 2100 (Thomas and Leason, 2005). Increased dust flux may increase aridity and suppress rainfall outside deserts, with opposite effects under wetting scenarios (Bachelet *et al.*, 2001; Hardy, 2003; Prospero and Lamb, 2003; Lioubimtseva and Adams, 2004), leading to indirect effects on the vulnerability of remote regions to climate change.

Key vulnerabilities: Winter-rainfall desert vegetation communities are vulnerable to drier and warmer conditions (Malcolm *et al.*, 2006; Simmons *et al.*, 2004). Up to 50% extinctions could occur with habitat elimination in the Chihuahuan desert (Lenihan *et al.*, 2003), while doubled CO_2 climate scenarios lead to a median 19.2% species extinction in South Africa's succulent Karoo Biome (Malcolm *et al.*, 2006).Using climate models and assuming a climate warming of 1.5 to 2°C about one third of the Sahel aridified by ~2050 t and vegetation zones generally shifted Equatorward (Box 4.3), though alternative climate scenarios showed less pronounced changes (van den Born *et al.*, 2004). Changing rainfall amounts and variability might favour the greater success of shrub species, and together with rising CO_2 may increase cover (Bachelet *et al.*, 2001; Hardy, 2003; Duraiappah *et al.*, 2005).

Box 4.3: Drought and Sahel ecosystems

The Sahel, a region bounded by the Great Sahara desert in the north and the Sudanian savanna in the south, has experienced large climate shifts in the past 6'000 years: during the mid-Holocene, wet conditions supporting mesic vegetation communities and abundant wildlife became markedly drier. A second change followed prolonged drought after 1969, and is used here, with caution as an analogue for potential future impacts of climate change (Foley *et al.*, 2003; ECF, 2004 WGI chapter 11). The major limitation in this approach is the lack of ecological changes dating back to before the drought began (Taylor *et al.*, 2002; Hein and Ridder, 2007). Under this recently established climate regime, the Sahel supports lower biomass than other arid lands with similar annual rainfall, e.g. the Kalahari Desert (Nicholson, 2002). Available water for plants is limited by soils that are prone to crusting and the highly unpredictable rains from seasonal monsoonal system (coefficient of variation > 20-30%, Hulme, 2001). Rains fall as high intensity convective events during the warm summer and, result in high potential evapo-transpiration (Turner, 1999; Hiernaux and Turner, 2002; Nicholson, 2002). Very low levels of nitrogen and phosphorus limit vegetative growth during wet years. Except for the transition zones in the south, the Sahel vegetation lacks the succulent, perennial grass and shrub forms typical of similar environments (Nicholson, 2000; Hiernaux and Turner, 2002). Instead, herbaceous species dominate as an annual grass layer, with few scattered trees and shrubs, due to the severity and long duration of the dry season (Lejeune *et al.*, 2004). Adaptive traits of annual plants to drought include short growing season, a large investment seed production – most of which are transient- and high tillering ability. Variation in yield and species composition is related to rainfall, effects of grazing history on soil properties and topography (Turner, 1999; Hiernaux and Turner, 2002). There are substantial variations in rain-use efficiency (RUE) between years for a given site. For E.g. C_3 Leguminous and other dicotyledonous species with lower RUE increase in wet years contributing to reduction of the RUE of the plant community over these periods (Hein and Ridder, 2007). Others suggest that the relatively constant RUE found in remote sensing studies (1982 -1990s) over different years may indicate a process of human induced degradation of the plant cover (Hein and Ridder, 2007). Atmospheric dust loads increase during drought years (30–50% of the total atmospheric dust loading, Nicholson, 2000).

Woody plant species in the Sahel have a diverse phenology but have shown drought induced mass mortality, and regeneration capacity in wet periods (Gonzalez, 2001; Hiernaux and Turner, 2002). Woody plants are increasingly being subjected to greater pressure from an increase in the proportion of small ruminants replacing tradition cattle as an adaptation to severe droughts in addition to production of charcoal and periodic wildfires (Woomer *et al.*, 2004). Recovery of land productivity from drought has been found for the Sahara/Sahel boundary tracking inter-annual fluctuations of rainfall. Infiltration and aquifer recharge occurred annually following the severe droughts (about 2 to 20% of rainfall) and this is believed to contribute to recovery of vegetation (Nicholson, 2000). However, extreme drought contributed to the decline of many Palearctic migratory birds that wintered in the savanna and steppe zones of the Sahel (Gitay *et al.*, 2001). A decrease in Sahel biodiversity and in some cases reactivation of vegetated dunes has also been noted (ECF, 2004).

Adaptation costs and opportunities: Taking advantage of for instance, wildlife species that will be favoured under climate change such as reptiles and amphibian richness, which can be accomplished through promoting eco-tourism (Currie, 2001; Reid *et al.*, 2005). Other eco-tourism related opportunities could include landform changes such as remobilised dunes (Thomas *et al.*, 2005). But the cost of these activities could be high due to lack of water, unbearable temperatures and increased problems of dust. While in wetter periods and also increase in temperature in cold deserts could provide opportunities for crop production.

There are no clear insights on adaptation option for migratory birds that cross deserts. For human needs autonomous adaptation could be cost effective (Allen Consulting Group, 2005). Because of unsuitable conditions for agriculture, deserts are current less transformed by human activity than other biomes. As a result a cost effective adaptation strategy might be to maintain deserts as there are i.e. with limited intervention (Balmford *et al.*, 2002). Where soil degradation has occurred, restoration efforts might provide carbon sequestration potential in soil and above ground biomass, but might be costly (Duraiappah *et al.*, 2005).

Implications for policy and sustainable development: If desert climates become more variable there will be greater need to incorporate climate change projections in designing future management policies. The effect of ecosystem degradation (desertification) on remote biomes i.e. through dust loads should also be considered in development plans. Sustainable utilization of deserts will require land use systems that minimize the destruction of soil to maintain water and nutrients cycles for plant growth (Duraiappah *et al.*, 2005). Prevention of land degradation might be cheaper than soil restoration.

Programs that focus on adjusting timing and intensity of grazing and fires where appropriate will minimise disturbances. Community participation in decision making and management along with public policy will be critical for adapting for E.g. adjusting stocking rates given the social value of animals in most desert societies, but also in addressing issues of diversification i.e. from livestock systems to eco-tourism (Duraiappah *et al.*, 2005).

Impacts summary as a function of ΔT:

- Median 19.2% endemic species extinction under a range of biological response scenarios and doubled CO_2 climate scenarios from GISS, GFDL-R30, OSU, UKMO, MPI-T106, HadCM2GHG, HadGCM2-SUL (Malcolm *et al.*, 2006).
- Karoo Desert bird species, Mountain Wheatear, projected range loss of 51% by 2050 (HadCM3 A2 Simmons *et al.*, 2004).
- Thirty percent of Sahel aridified, vegetation zones shifted Equatorward; warming of 1.5 to 2°C (van den Born *et al.*, 2004).
- Kalahari desert dune system remobilized with regional warming of between 2.5 to 3.5^0C (Thomas and Leason, 2005).

4.4.3 Grasslands and savanna

Characteristics: These include tropical C_4 grasslands and savannas (C_4 grass-dominated with 10-50% tree cover, ~28 million km^2) and temperate C_4 and/or C_3-grass and herb-dominated grasslands (15 million km^2) (Bonan, 2002). These systems are disturbance-controlled, by fire (Bond *et al.*, 2005) and/or grazing (Fuhlendorf *et al.*, 2001; Scholes and Archer, 1997). These disturbance regimes are often managed, though fire regimes depend on seasonality of ignition events and rainfall (Brown *et al.*, 2005b).

Goods and services: (Hassan *et al.*, 2005) Supporting services – soil preservation, soil nutrient cycling and conservation, and primary production; Regulating services – water and climate regulation; Provisioning services – food (rangeland grazing and wild foods, fuel, fibre and construction material, biochemicals, freshwater; Cultural services – recreation and ecotourism, extensive animal diversity, especially in Africa, that in turn support nature-based tourism, wildlife ranching, and hunting.

Key vulnerabilities as from TAR: Reviewed as rangelands in TAR, and included deserts. Major threats include fragmentation of land cover, over-grazing and changing fire regimes;extensive ranching threatened by climate change, though greater threat from land-use change; impacts of rising CO_2 on ecosystem vegetation structure and fuel availability, with possible increases in carbon sequestration dependent on management regimes. Soil stability and desertification, especially on arid margins. Lack of infrastructure and investment in resource management increases vulnerability.

Impacts: Climate and atmospheric change will affect grassland and savanna ecosystem function and species composition through the relative physiological and growth responses of their component species and growth forms to rainfall change, CO_2 fertilization, warming, and emergent responses of herbivory and fire regime. Few experimental approaches have assessed ecosystem responses to multifactorial treatments such as these (Norby and Luo, 2004). Experiments on warming, rainfall change or atmospheric CO_2 level are virtually absent in savannas; many field-based ecosystem studies are confined to grasslands (Rustad *et al.*, 2001).

Temperate and alpine grassland responses to future climate change may be strongly controlled by hydrological cycle and water balance change (Novick *et al.*, 2004; Zha *et al.*, 2005). A Canadian grassland fixed roughly 5x as much carbon in a year with 30% higher rainfall, while a 15% rainfall reduction led to a net carbon loss (Flanagan *et al.*, 2002). A European grassland showed only minor responses to 3ºC rise in temperature possibly due to compensating drying impacts (Gielen *et al.*, 2005). A Mongolian steppe grassland switched from carbon sink to source in response to water stress (Li *et al.*, 2005). Net ecosystem carbon exchange in a North Oklahoma grassland was dependent on intra and inter-seasonal rainfall change (Suyker and Verma, 2001; Suyker *et al.*, 2003). Increased rainfall variability was more significant than rainfall amount for tall-grass prairie productivity (Fay *et al.*, 2000; Fay *et al.*, 2002), with 50% increased dry spell duration causing 10% reduction in NPP (Fay *et al.*, 2003) and 13% reduction in soil respiration (Harper *et al.*, 2005). Ecosystem models of C_3/C_4 mixed grasslands show positive NPP relationships with moderate rainfall variability (with unchanged MAP), but greater variability reduces both NPP and ecosystem stability (Mitchell and Csillag, 2001); empirical results for C_4 grasslands show a similar monotonic relationship between NPP and rainfall variability (Nippert *et al.*, 2006). Varying both winter and summer precipitation had immediate and carry-over effects on short grass prairie respiration rate (Chimner and Welker, 2005). Both plant cover and productivity reductions were simulated along an aridity gradient in southern African savanna in response to the drying trend of ~8 mm yr^{-1} since 1970 (MAR ranged from 299 to 918 mm yr-1 in 2000 Woodward and Lomas, 2004a). Changing savanna vegetation cover may also feed back to affect regional rainfall patterns. Modeled removal of savanna systems from global vegetation cover has larger effects on global precipitation than for any other biome (Snyder *et al.*, 2004). In four out of five savanna systems studied globally, modeled conversion of savanna to grassland resulted in a 10% rainfall reduction, suggesting a positive feedback between anthropogenic impacts and changing climate (Hoffmann and Jackson, 2000). At the continental scale, modeled conversion of tropical forest to savanna reduced rainfall in tropical regions, but increased rainfall in central southern Africa (Semazzi and Song, 2001).

Increasing dominance of C_4 grasses at the expense of C_3 forms such as herbs, shrubs and trees may occur in response to warming (Epstein *et al.*, 2002), relevant for C_4 invasions accelerated by human disturbance and fire (Sage and Kubien, 2003). Some African savanna tree phenologies appear sensitive to seasonal air temperatures (Chidumayo, 2001). Less than 4ºC warming show woody vegetation expanding with positive carbon sequestration in North America, but waning with greater warming, partly due to fire, with up to 50% expansion of savannas at the expense of forests (Bachelet *et al.*, 2001). Warming of a mixed C_3/C_4 New Zealand grassland to simulate extreme heat wave events increased C_4 species success within a single growing season, but reduced productivity by over 60% where C_4 plants were absent (White *et al.*, 2000b). Drying, increased wind speed, and warming of 2.5ºC to 3.5ºC by 2100 reduce vegetation cover and remobilize Kalahari dune systems in southern Africa as early as 2040 (Thomas *et al.*, 2005).

Transient system responses to the IS92a scenario reduced mid-latitude carbon sinks (partly in savanna systems) that offset increasing carbon sinks at high latitudes, leading to a net global carbon source from vegetation (White *et al.*, 2000a). This effect was muted and delayed by more than a century if atmospheric [CO_2] stabilized at 550 ppm. Suggestions that rising atmospheric CO_2 would differentially favour C_3 types in mixed C_3/C_4 grasslands have not been conclusively supported by experiments (Wand *et al.*, 1999). In short-grass prairie, field CO_2 fumigation and 2.6ºC warming increased production by 26-47% , regardless of photosynthetic type (Morgan *et al.*, 2001a). In C_4 tropical grassland, decades-long CO_2 enrichment also revealed no increase in C_3 success (Stock *et al.*, 2005). Both field studies showed increased soil water content at elevated CO_2 (see also Ferretti *et al.*, 2001). Elevated CO_2 stimulation of productivity in chalk grasslands can be attributed to effects on stomatal conductance and short term increased soil water (Niklaus and Koerner, 2004). Increasing temperature and rainfall changes may override the potential benefits of rising CO_2 for C_3 relative to C_4 grasses (Winslow *et al.*, 2003). In Namibian savannas, rising CO_2 may favour shrubs and herbs at the expense of C_4 grasses (Thuiller *et al.*, 2007a). Current and future atmospheric CO_2 levels may reduce the historic vulnerability of Sahelian systems to drought, by facilitating increased primary productivity and water balance through CO_2 fertilization (Wang and Eltahir, 2002). Regional climate modeling indicates that the biological impacts of CO_2 fertilization on grasslands may scale up to affect regional climate (Eastman *et al.*, 2001).

Temperate grassland carbon sequestration likely increased strongly in response to increases of CO_2 from glacial to interglacial levels (Gill *et al.*, 2002), but increases of 54% in net fixation expected CO_2 doubles (Hsieh *et al.*, 2005). Both NPP and carbon stocks are modeled to increase in response to both elevated CO_2 and warming, except with positive precipitation changes at cool sites (Riedo *et al.*, 2000). Elevated CO_2 impacts on temperate grassland carbon sequestration are also dependent on management (Harmens *et al.*, 2004; Jones and Donnelly, 2004), and nutrient amendment, complicated by being species- but not functional-type specific (Niklaus *et al.*, 2001; Hanley *et al.*, 2004). Tropical savanna NPP is second only to that of tropical forests, yet they maintain only a quarter of the above-ground biomass of tropical forests because of fires, and are therefore a potential carbon sink contingent on fire regime. For example, Australian savanna systems are currently a net carbon sink of between 1 and 3 t C ha^{-1} y^{-1}, depending on the frequency and extent of fire (Williams *et al.*, 2004b). Fire exclusion has the potential to transform savannas to forests (observed by e.g.Bowman *et al.*, 2001), and could result in an increase of closed forest cover from current 27% to 56% of the vegetated surface of the world (Bond *et al.*, 2005).

Tree-grass balance in savannas may be shifting towards trees with continuously rising atmospheric CO_2 concentrations, and diminishing ability of grasses to suppress ever faster growing tree saplings in grass fires (Bond and Midgley, 2000; Bond *et al.*, 2003). However, there are no field tests of this hypothesis, and other factors such as long-term grazing pressure may explain observed shrub encroachment (Van Auken, 2000). Encroachment of woody plants in grasslands and savannas may increase carbon sequestration, not only by standing crop, but also by increased carbon sequestration in soils dried by greater transpiration (Huxman *et al.*, 2005) especially in drier sites (e.g. McCarron *et al.*, 2003); wetter sites lose enough soil carbon to offset greater standing crop (Jackson *et al.*, 2002). Woodland expansion also reduces soil carbon turnover rate by almost 40% through soil cooling, leading to potential reduction in soil efflux of $19x10^6$Mg C yr^{-1} in the US Great Plains with canopy closure (Smith and Johnson, 2004).

Field experiments reveal impacts on soil, and nutrient controls of vegetation response. Long term CO_2 fumigation of southern African C_4 grassland revealed muted impacts on nitrogen cycling and soil C sequestration (Stock *et al.*, 2005), in contrast to greater C sequestration in short term studies of grassland ecosystems (e.g. Williams *et al.*, 2004a). Elevated CO_2 impacts on litter decomposition seem species-specific and relatively minor (Ross *et al.*, 2002)but may cascade through the soil food web (Hungate *et al.*, 2000). Acclimatization of soil respiration to moderate warming suggests a low feedback potential of ecosystem respiration to atmospheric CO_2 composition (Luo *et al.*, 2001; Edwards *et al.*, 2004). However, complex interactions between plants and fungal symbionts showed potential impacts on soil structure that may predispose them to accelerated erosion (Rillig *et al.*, 2002). Warming of a tallgrass prairie showed increased plant growth, funding enhanced soil fungal success (Zhang *et al.*, 2005).

Climate change impacts studies for savanna and grassland fauna are few. Substantial community compositional shifts of African mammal faunas have been projected for 2050 and 2080, including substantial increases in critically endangered and extinct species to between 10 and 40% of mammal species (Thuiller *et al.*, 2006). For an African arid savanna raptor, general reductions in population success have been simulated under climate change scenarios (Wichmann *et al.*, 2003). A 4% to 98% reduction in species ranges for ~80% of 179 animal species have been projected using IS92a-driven regionally interpolated climate scenarios, including many savanna birds and mammals (Erasmus *et al.*, 2002). Observed population declines in three African savanna ungulates suggest that summer rainfall reductions could result in their local extirpation if regional warming continues (Ogutu and Owen-Smith, 2003).

Adaptation costs and opportunities: Similar to other chapters

Key vulnerabilities:
- Shifts in vegetation structure driven by water, CO_2 and temperature changes, with potential non-linear impacts with increasing climate change, and associated impacts on habitat-dependent fauna.
- Accelerating fire frequency and fire size due to more common warmer, drier fire danger weather, and greater fine herbaceous fuel accumulation with increasing rainfall and CO_2 fertilization.
- Projected shifts in species geographic ranges threatened by landscape fragmentation through land use change, especially of large mammals with large range requirements, threats to fauna limited in migration potential by restrictive protected area networks.

Impacts summary as a function of ΔT:
- North America: < 4ºC, woody vegetation expands, positive carbon sequestration, >4ºC up to 50% expansion of savannas at the expense of forests (Bachelet *et al.*, 2001).
- Africa: 2.5ºC to 3.5ºC by 2100, reduction in vegetation cover and remobilization of Kalahari dune systems in southern Africa as early as 2040 (Thomas *et al.*, 2005).
- Africa: HadCM3 A2, 2050 and 2080, Mammal community compositional shifts, increases in critically endangered and extinct species to between 10 and 40% of mammal species (Thuiller *et al.*, 2006).
- Africa: Rainfall variability scenarios: African arid savanna raptor, reduced population success (Wichmann *et al.*, 2003).
- Africa: IS92a Gga (HADCM2-SUL) 4% to 98% reduction in species ranges for ~80% of 179 animal species (Erasmus *et al.*, 2002).

4.4.4 Mediterranean ecosystems

Characteristics: Mid-latitudes on all continents, in coastal regions (Mediterranean basin, Baja Mexico/California, south-western South Africa, south-western and southern Australia, central Chile), covering ~ $3.4 \times 10^6 km^2$. Climatically distinct with generally wet winters and dry summers, often on nutrient-poor soils (Cowling *et al.*, 2005) and with high levels of biodiversity (Cowling *et al.*, 1996). Generally shrub-dominated, but woodlands, forests and even grasslands occur in limited regions, and in the Mediterranean basin and increasingly elsewhere, heavily utilized landscapes are dominated by grasses, herbs and annual plant species where human impacts have favored disturbance-tolerant floras (Lavorel, 1999). Generally fire-prone, due to dry summers (Montenegro *et al.*, 2004).

Goods and services: Valuable for high biodiversity overall (Myers *et al.*, 2000), but also for grazing in the Mediterranean basin and Chile, products of extractive harvesting (e.g. wildflowers in South Africa and Australia, now also commercially produced for international trade), water yield for human consumption and agriculture in South Africa, and ground cover services on otherwise generally unproductive nutrient-poor soils.

Key vulnerabilities as from TAR: Mediterranean systems were not explicitly reviewed, but threats from desertification were projected due to expansion of adjacent semi-arid and arid systems under relatively minor warming and drying scenarios.

Impacts: These systems may be among the most impacted by global change (Sala *et al.*, 2000). Diverse Californian vegetation types may show substantial cover change for temperature increases greater than about 2°C, including desert and grassland expansion at the expense of shrublands, and mixed deciduous forest expansion at the expense of evergreen conifer forest (Hayhoe *et al.*, 2004). The Cape Fynbos Biome could lose 65% area under warming of 1.8°C, with ultimate species extinction of 23%

resulting in the long term (Thomas *et al.*, 2004b; Rutherford *et al.*, 2000). For Europe, only minor biome-level shifts are projected for Mediterranean vegetation types for GMT increase of 3.2°C (Parry, 2000), contrasting with between 60 and 80% of current species projected not to persist in the southern European Mediterranean region (GMT increase of 1.8°C, Bakkenes *et al.*, 2002). Inclusion of CO_2 fertilization effects in biome-level modelling may partly explain this contrast. Land abandonment trends facilitate ongoing forest recovery (Mouillot *et al.*, 2003) in the Mediterranean Basin, complicating projections. In southwest Australia, high rates of vegetation migration rates may be induced under double CO_2 scenarios (Malcolm *et al.*, 2002), and habitats of all frogs and many mammal species would contract significantly with only a 0.5°C warming (Group, 2005).

Climate change impacts will interact with fire regime shifts. Greater fire frequencies are noted in Mediterranean basin regions (Pausas and Abdel Malak, 2004) with exceptions (Mouillot *et al.*, 2003). Double CO_2 scenarios increase fire escapes by 40-50% in California (Fried *et al.*, 2004), and double fire risk in western Fynbos (Midgley *et al.*, 2005), favoring sprouting plants over seed regenerators in Fynbos (Bond and Midgley, 2003), fire-tolerant shrub dominance in the Mediterranean Basin (Mouillot *et al.*, 2002), and vegetation structural change in California (needle-leaved to broad-leaved trees, trees to grasses) reducing productivity and carbon sequestration (Lenihan *et al.*, 2003).

Significant warming trends have been noted in the Cape Floristic Kingdom (Warburton *et al.*, 2005) and the Mediterranean Basin (Rebetez, 2004), extending growing season by 16 days (Penuelas and Filella, 2001). Experimental warming shifted species relative dominance in Mediterranean Basin communities (Wessel *et al.*, 2004).

Projected rainfall changes are spatially complex (e.g. Sanchez *et al.*, 2004; Sumner *et al.*, 2003; Vicente-Serrano *et al.*, 2004). Rainfall frequency reductions projected for some Mediterranean regions (e.g. Cheddadi *et al.*, 2001) will exacerbate drought conditions. Soil water content controls ecosystem water and CO_2 flux in the Mediterranean Basin system below key water content thresholds (Rambal *et al.*, 2003), and could reduce ecosystem carbon and water flux (Reichstein *et al.*, 2002). The 2003 European drought had major physiological impacts on Mediterranean vegetation and ecosystems, but most showed a full recovery by 2004 (Gobron *et al.*, 2005). A mediterranean dryland ecosystem showed net losses of carbon in dry years (Hastings *et al.*, 2005).

With increasing precipitation, forest expansion and greater carbon storage has been projected in California (Bachelet *et al.*, 2001). In the Mediterranean basin, vegetation structural change will depend on rainfall change, with possibly increased forest success in the eastern Mediterranean and Turkey, and increased shrub cover in northern Africa if rainfall does not decrease (Cheddadi *et al.*, 2001).

Many species show marginal benefits from rising atmospheric CO_2 (Dukes *et al.*, 2005), and limited increases in above-ground productivity (e.g. Blaschke *et al.*, 2001). Ecosystem carbon storage may increase due to reductions in litter decomposition rate induced by elevated CO_2 (De Angelis *et al.*, 2000).

Established *Pinus halepensis* (Borghetti *et al.*, 1998) show high drought resistance, but Ponderosa pine forests had reduced productivity and water flux during a 1997 heatwave, which did not recover for the rest of the season, indicating threshold responses to extreme events (Goldstein *et al.*, 2000). Mediterranean Basin pines (Martinez-Vilalta and Pinol, 2002) and other woody species (Penuelas *et al.*, 2001), showed species-specific drought tolerance under field conditions. Experimental drying differentially reduced productivity of Mediterranean basin shrub species (Llorens *et al.*, 2003; Llorens *et al.*, 2004; Ogaya and Penuelas, 2004) and tree species (Ogaya and Penuelas, 2003), and even the flowering phenology of Mediterranean basin shrub species (Llorens and Penuelas, 2005), suggesting complex changes in species relative success under drying scenarios. Species-specific tolerance to drought in woody plants may be explained by xylem hydraulic characteristics (Martinez-Vilalta *et al.*, 2002). Drought may also act indirectly on plants by reducing the availability of soil phosphorus (Sardans and Penuelas, 2004).

Bioclimatic niche-based modeling projects reduced species persistence, species richness, and range reductions for the majority of species modeled in the Cape Floristic Region (Midgley *et al.*, 2002; Midgley *et al.*, 2003). Ranges of trees and shrubs may shift unpredictably, and fragment, under IS92a scenarios (Shafer *et al.*, 2001). In southern Europe, species composition change may be high under a range of scenarios (Thuiller *et al.*, 2005). Range size reductions increase species extinction risks, with up to 30-40% facing increased extinction probabilities beyond 2050 (Thomas *et al.*, 2004a). Species of lowland plains may be at higher risk than montane species both in California (Peterson, 2003) and Cape Floristic Region (Midgley *et al.*, 2003), although in the Mediterranean Basin, montane species show high risk (Thuiller *et al.*, 2005).

Adaptation costs and opportunities: Adaptation strategies include optimising species persistence through identifying key geographic regions for higher levels of species protection (Hannah *et al.*, 2005), and to facilitate species migration in protected areas (Williams *et al.*, 2005). Costs have not been estimated.

Key vulnerabilities: Warming and drying trends threaten substantial species range reductions and imply a need for high rates of migration to allow natural adaptation, unlikely to be realized. Land-use, habitat fragmentation and intense human pressures will further limit natural adaptation responses, and fire regime shifts may threaten specific species and plant functional types. Vegetation structural change driven by dominant, common or invasive species may also threaten rare species. Overall a loss of biodiversity and carbon sequestration services may be realized over much of these regions.

Impacts summary as a function of ΔT: Diverse vegetation types of California are projected to show substantial shifts in cover for temperature increase in excess of about 2°C, including desert and grassland expansion at the expense of shrublands, and mixed deciduous forest expansion at the expense of evergreen conifer forest (Hayhoe *et al.*, 2004). Cape Fynbos Biome reduced in area by 65% (climate scenario HADCM2 n IS92a, for 2050). In southwest Australia, high rates of vegetation migration rates may be induced under double CO_2 scenarios (Malcolm *et al.*, 2002), and the habitats for all frog and many mammal species would be significantly reduced with only a 0.5°C warming (Group, 2005). Double CO_2 scenarios increase fire escapes by 40-50% in California (Fried *et al.*, 2004), and double fire risk in western Fynbos (Midgley *et al.*, 2005).

Implications for policy and sustainable development: [for DGVM section: Rising atmospheric CO_2 may counteract some effects of drying trends on plant primary productivity (Ainsworth and Long, 2005; Drake *et al.*, 1997), and may already have counteracted negative impacts of climate trends during the 20th century.

4.4.5 Forests and woodlands

Characteristics: Ecosystems with a densely treed canopy, covering a total of 41.6 Mkm^2 (~30% of all land) with 42% in the tropics, 25% in the temperate, and 33% in the boreal zone (Table 4.1, e.g. Sabine *et al.*, 2004). Forests require benign environmental conditions (summer means >12°C, >300 mm total annual rainfall) and are among the most productive terrestrial ecosystems (Table 4.1). This makes them attractive both for agricultural uses (underlying the currently high deforestation and degradation rates in tropical and subtropical regions Hassan *et al.*, 2005; leading to about one quarter of anthropogenic CO2 emissions e.g. Houghton, 2003a), and also for climate change mitigation purposes (WG III Chapter 11, Watson *et al.*, 2000). Nevertheless, forests, in particular the northern circumpolar boreal forests (70.2 Pg (~30%) Smith *et al.*, 2004), still store in plant biomass and soils the largest portion of biospheric carbon stocks, recently estimated as high as 1'640 PgC (Sabine *et al.*, 2004), corresponding to ~220% of atmospheric carbon.

Goods and services: In addition to well known commercial goods (Chapter 5 Shvidenko *et al.*, 2005 Section 21.5 p.600-607) forests provide numerous goods for subsistent livelihoods, especially for the rural poor (Gitay *et al.*, 2001 p. 239; Shvidenko *et al.*, 2005). Many key supporting services essential for human existence are less recognised, such as habitat provision for an increasing fraction of biodiversity (in particular where subject to land-use pressures Hassan *et al.*, 2005; Duraiappah *et al.*, 2005). Carbon sequestration dominates regulating services, due to high forest productivity, but numerous other regulating services are as essential for human well-being: climate regulation, soil and water protection or purification (>75% of globally usable freshwater supplies come from forested catchments Shvidenko *et al.*, 2005), and recreational, cultural, and spiritual services (Reid *et al.*, 2005; Millennium Ecosystem Assessment, 2005c).

Key vulnerabilities as from TAR: Forests, in particular in the boreal region, were considered to have a high potential vulnerability to climate change, which would only become apparent in the long-term unless disturbance regimes (drought, insects, fire), partly due to climate change, were to cross critical thresholds (Gitay *et al.*, 2001).

Impacts: Projections for some forests currently limited by their minimum climatic requirements indicate gains from climate change (references at end of sentence; Fig. 4.4, vegetation changes (VC) 1 to 3), but many may be impacted detrimentally (Fig. 4.4 VC 6), notably for stronger warming (Kirschbaum and Fischlin, 1996; Matarira and Mwamuka, 1996; Bugmann, 1997; Fischlin and Gyalistras, 1997; Solomon and Leemans, 1997; Foley *et al.*, 1998; Ravindranath and Sukumar, 1998; Lischke *et al.*, 1998; Villers-Ruiz and Trejo-Vazquez, 1998; Dixon *et al.*, 1999; Price *et al.*, 1999; Siddiqui *et al.*, 1999; Still *et al.*, 1999; White *et al.*, 1999; Daly *et al.*, 2000; Flannigan *et al.*, 2000; Ni *et al.*, 2000; White *et al.*, 2000b; Bachelet *et al.*, 2001; Bergengren *et al.*, 2001; Ostendorf *et al.*, 2001; Smith and Lazo, 2001; Xu and Yan, 2001; Arnell *et al.*, 2002; Enquist, 2002; Iverson and Prasad, 2002; Bachelet *et al.*, 2003; Lauenroth *et al.*, 2004; Levy *et al.*, 2004; Izaurralde *et al.*, 2005; Schaphoff *et al.*, 2006; Scholze *et al.*, 2007 compare VC 6 Fig. 4.4a vs. b). Average productivity gains result from CO2 fertilization (although this effect has shown to be much weaker than previously assumed, see 4.4.1), warming in cold climates given concomitant precipitation increases do compensate for possibly increasing water vapour pressure deficits, and precipitation increases under water limited conditions. There is growing evidence that nutrients (e.g. enrichment as resulting from N deposition), species composition, dynamic age structure effects (albeit often poorly mimicked by several models from above cited studies, in particular at the global scale), pollution, and biotic interactions such as soil organisms, may moderate the direct CO_2 or climate change effects affecting in particular also the net ecosystem productivity (e.g. Karnosky *et al.*, 2003; King *et al.*, 2004b; Heath *et al.*, 2005; Körner *et al.*, 2005a 4.4.1). Impacts of climate change on forests, in particular detrimental ones, however, depend not only on climate means, but also on the seasonal and diurnal rainfall and temperature patterns and may be moderated by the hydrological regime as influenced by the hydrologically relevant surroundings of a forest stand (e.g. Zierl and Bugmann, 2005). Furthermore, precipitation is distributed worldwide in a highly uneven manner (WG I Chapters 9, 10) and thus conditions forests may experience in future climate change are associated with major uncertainties. While the upper bound for precipitation is of minor concern, since extreme persistent flooding alone results in tree mortality, the upper bound for temperature is more critical, since it is linked to precipitation in a complex, non-linear manner. In some regions such as Central and Northern Europe in addition to warming more winter precipitation was observed in the past (e.g. Gyalistras, 2003; Xoplaki *et al.*, 2003) and is projected for the future (WG I, chapter 9, 10). However, since summer temperatures are projected to increase and precipitation to decline, there is potential for drought conditions during the critical growing phase, which is true for many locations on all continents (e.g. Cox *et al.*, 2004; Schaphoff *et al.*, 2006; Scholze *et al.*, 2007 Fig. 4.4 VC 6). Since all these responses potentially influence net forst carbon exchange (NEP), substantive biotic feedbacks may result, either through carbon releases or influences on regional climate contributing to further major uncertainties (e.g. Betts *et al.*, 2000; Peng and Apps, 2000; Grace and Rayment, 2000; Gitay *et al.*, 2001; Semazzi and Song, 2001; Bergengren *et al.*, 2001; Rasmussen *et al.*, 2002; Leemans *et al.*, 2002; Wicks and Curran, 2003; Korner, 2003b; Cox *et al.*, 2004; Korner, 2004; Canadell *et al.*, 2004; Gruber *et al.*, 2004; Heath *et al.*, 2005; Körner *et al.*, 2005a; Leuzinger *et al.*, 2005; Körner, 2007).

Effects of drought on forests, including resulting biotic feedbacks, remain incompletely understood (e.g. Reichstein *et al.*, 2002; Betts *et al.*, 2004). While increased mortality is a likely consequence of severe drought, impacts can be offset by fertile soils (Hanson and Weltzin, 2000). Moreover, the European heat wave 2003 (Box 4.1) enhanced growth at high elevation sites (Jolly *et al.*, 2005) and more benign conditions in 2004 allowed forests to partly recover (Gobron *et al.*, 2005; somewhat contested by Lloret *et al.*, 2004), whereas contemporaneous drought was found to deplete resilience of e.g. Mediterranean forests (Lloret *et al.*, 2004 4.4.4).

Drought conditions interact with disturbances such as fire (Flannigan *et al.*, 2000) or insects (Hanson and Weltzin, 2000; Logan *et al.*, 2003 Box 4.1). For instance, in boreal forest, tree defoliating insects affect an area about 50 times as large as that subject to fire (Logan *et al.*, 2003) and can periodically cause economically as well as ecologically substantive damages (e.g. Gitay *et al.*, 2001 Box 5-10). Insect pests are at least partly responsible for the decline and ultimate extirpation of stands at the southern margins of the range of their hosts, subject to warmer and drier conditions, where outbreaks occur at a higher frequency (Volney and Fleming, 2000). If climate warms and this ecotone becomes subject to increased drought, the effect is expected to become stronger (Gan, 2004; Logan *et al.*, 2003). At the northern ecotone, frosts and the cold temperature in general appear to limit insect outbreaks (Virtanen *et al.*, 1996; Volney and Fleming, 2000), implying that oubreaks currently constrained from northern ranges will become more frequent in a warming world (Carroll *et al.*, 2004). In general it is difficult to project overall effects of climate change on pest insects, since these are affected by temperature, humidity, and biotic interactions in a species-specific manner, which may perturb poorly understood ecological interactions such as natural biological control, tipping the balance on population control positively or negatively (Malmstrom and Raffa, 2000; Bale *et al.*, 2002; Morecroft *et al.*, 2002), whereas for diseases some findings suggest an increase in infected areas or increased abundances (e.g. Boland *et al.*, 2004; Bergot *et al.*, 2004).

Climate change is known to alter some disturbance regimes directly, e.g. increasing wildfire frequencies and event extents (e.g. Stocks *et al.*, 1998; Podur *et al.*, 2002; Gillett *et al.*, 2004; Brown *et al.*, 2004), but climate change induced stress on trees may also indirectly exacerbate disturbances (Dale *et al.*, 2000). Relationships between storms and climate change are still poorly understood (WG I, Box 4.2, ice storms Irland, 2000), however windthrow impacts can be substantive (e.g. Peterson, 2000; Thurig *et al.*, 2005b; Fuhrer *et al.*, 2007), and for southern Finland some findings suggest increased susceptibility to windthrow by climate change (Peltola *et al.*, 1999). Considerable progress has been made in understanding fire regimes and related processes (Kasischke and Stocks, 2000; Skinner *et al.*, 2002; Stocks *et al.*, 2002; Hicke *et al.*, 2003; Podur *et al.*, 2003; Wotton *et al.*, 2003; Gillett *et al.*, 2004) enabling improved projections of future fire regimes (Li *et al.*, 2000; Flannigan *et al.*, 2000; de Groot *et al.*, 2003; Fried *et al.*, 2004; Brown *et al.*, 2004). Some authors (Flannigan *et al.*, 2000) argue that altered fire regimes will impact boreal forests more than climate change itself. Climate changes including in El Niño events may also alter fire regimes in fire-prone regions such as Australia (Hughes, 2003; Williams *et al.*, 2004b; Allen Consulting Group, 2005) the Mediterranean region (e.g. Mouillot *et al.*, 2002 see 4.4.4) or as far North as Alaska (Hess *et al.*, 2001). Finally, fire may severely impact the tundra (Rupp *et al.*, 2000; Camill and Clark, 2000), possibly releasing large quantities of CO_2 from carbon previously immobilized in frozen soils (Harden *et al.*, 2000) which have accumulated to one of the largest carbon stocks in the biosphere since the last ice age (Smith *et al.*, 2004).

Rapid encroachment of boreal tree species into present tundra could compensate for such losses. Vegetation models project that forest might replace between 11 and 50% of tundra over the period in which atmospheric CO_2 doubles (Harding *et al.*, 2002; Kaplan *et al.*, 2003; White *et al.*, 2000b; Callaghan *et al.*, 2005 Fig. 4.4 VC 1). However, estimates for migration rates of tree species from paleoecological records (as low as 10-25 m/yr for Norway spruce Udra, 1988; on average 200-300 m/yr, up as high as 500-1,000 m/yr for pioneers, or exceptionally 2,000 m/yr, Davis, 1981; Velichko *et al.*, 1995; Ritchie and MacDonald, 1986; Kirschbaum and Fischlin, 1996; Symon *et al.*, 2005 p. 570) and modelling studies reconstructing past (e.g. Solomon and Kirilenko, 1997; Prentice and Jolly, 2000; Lischke *et al.*, 2002) or projecting future (Iverson *et al.*, 2004; Neilson *et al.*, 2005) dispersal, all indicate that more realistic migration rates will result in lagged northward shifts of taiga (150-250 yr Chapin and Starfield, 1997; Camill and Clark, 2000; Skre *et al.*, 2002). Lower rates are probably realistic, since higher estimates typically ignore delaying factors such as herbivory or soil formation processes (Vlassova, 2002; Crawford *et al.*, 2003; Nordengren *et al.*, 2003; Cairns and Moen, 2004; Juday, 2005 see 4.4.6) and recent genetic analysis (McLachlan *et al.*, 2005) indicates that commonly inferred estimates from pollen have overestimated dispersal rates, explaining observed pollen records by multifront recolonization from low-density refugees (Pearson, 2006). Slow encroachment of taiga into tundra is confirmed by satellite data showing no expansion of boreal forest stands in response to recent warming (Masek, 2001). Simultaneously, the rate of boreal forests loss at the southern boundary due to drought and fire (e.g. Kurz and Apps, 1999) indicates an incipient lag, with projections of major carbon losses, in particular from peatlands, with the potential to accelerate global climate change (e.g. Woodwell *et al.*, 1998; Camill and Clark, 1998; Camill and Clark, 2000; Grant *et al.*, 2003 4.4.6).

As reported in TAR (Gitay *et al.*, 2001) the net global loss in forest cover appears to have slowed further (Stokstad, 2001; FAO, 2001), but in some tropical and subtropical regions, notably Southeast Asia and similarly the Amazon (e.g. Nepstad *et al.*, 1999), deforestation rates are still high (0.01-2.01%/yr Lepers *et al.*, 2005; Alcamo *et al.*, 2007), while in some northern regions like Siberia, degradation rates are increasing largely due to non-sustainable logging (Lepers *et al.*, 2005). Though uncertainties for rate estimates are considerable (e.g. FAO, 2001; Houghton, 2003b; Lepers *et al.*, 2005), current trends in pressures (Nelson, 2005) will clearly lead to continued deforestation and degradation in critical areas (historically accumulated loss of 182–199 PgC DeFries *et al.*, 1999; Canadell *et al.*, 2004; Shvidenko *et al.*, 2005; expected releases in 21st century 40 – 100 PgC Gruber *et al.*, 2004) with concomitant implications for biodiversity (Duraiappah *et al.*, 2005) and other supporting services (Hassan *et al.*, 2005).In most industrialized countries forest areas are expected to increase (e.g. European forests by 2080 up to 6% for SRES B2, Karjalainen *et al.*, 2002; Sitch *et al.*, 2005) partly due to intensified, agricultural management and climate change.

Although land use changes may dominate impacts, especially in biodiversity hotspots, climate change generally exacerbates biodiversity risks (montane cloud forests Foster, 2001; Amazonia Miles, 2002; Hawai Benning *et al.*, 2002; Costa Rica Enquist, 2002; Australia Williams *et al.*, 2003) including tropical montane cloud forests where extinction of amphibian species has been attributed as very likely caused by recent climate change (Pounds *et al.*, 2006). In a few exceptions climate change may increase diversity locally or regionally (Kienast *et al.*, 1998) but in most cases extinction risks are increased and conservation management practices need to adapt to prevent this (e.g. Villers-Ruiz and Trejo-Vazquez, 1998; Bazzaz, 1998; Thompson *et al.*, 1998; Malhi and Phillips, 2004).

Adaptation costs and opportunities: Few studies exist (e.g. Winnett, 1998) and quantitative estimates, i.e. model projections, diverge and prevent conclusive findings (Winnett, 1998).

Key vulnerabilities: Most scenarios based on an A2 world show significant forest dieback towards the end of this century and onwards in tropical, boreal, and mountain areas with a concomitant loss in diversity as well as key services such as local climate regulation and C sequestration. These forests also harbor a major fraction of Earth's biodiversity, in particular tropical forest diversity hotspots (e.g. northeastern Amazonia Miles, 2002). Mountain forests are increasingly encroached upon from adjacent lowlands, while simultaneously losing high altitude habitats due to warming.

Impacts summary as a function of ΔT:

- > 1°C substantive fraction of stands with severe climate change impact (Lexer *et al.*, 2002).
- > 1°C high sensitivity of humid tropical forests of north Queensland, Australia (Hilbert et al., 2001).

4.4.6 Tundra and arctic ecosystems

Characteristics: "Tundra" is used here in its widest sense to denote vegetation and ecosystems north of the treeline of closed boreal forest, (tundra's southern transition zone) which occurs at about 51°N in eastern Canada to about 84°N in Greenland (Callaghan *et al.*, 2005). This includes any ecosystems poleward from tundra, notably the sea ice biome in both hemispheres (e.g. Arrigo and Thomas, 2004 see 4.4.9), and Southern Ocean sub-antarctic islands, which enables an otherwise desert-like ice environment with the needed primary production to support life-forms up to top predators such as polar bears (Box 4.4).

Goods and services: Arctic ecosystem services include climate regulation, biodiversity maintenance, fuel, food and fibre production, and cultural enjoyment (Chapin *et al.*, 2005a p. 721-728). Climate regulation is likely to be dominated by positive feedbacks between climate and albedo changes through diminishing snow covers and expanding forests or woodlands (Chapin *et al.*, 2005b) plus changes in the greenhouse gas balance, notably of methane (Christensen *et al.*, 2004). The arctic harbors unique species (e.g. Box 4.4) contributing to global biodiversity (Usher *et al.*, 2005; Chapin *et al.*, 2005a), and are important as a renewable resource for local livelihoods. Local mixed economies of cash and subsistence depend strongly on household production, which involves the harvest of local resources, food preparation, storage, distribution, and consumption, all forming part of a intergenerational transmission of a unique body of knowledge (Hassol, 2004a).

Key vulnerabilities as from TAR: Arctic and sub-arctic ecosystems (ombrotrophic bog communities) above permafrost were considered likely to be most vulnerable to climatic changes, since impacts may turn arctic regions from a net sink to a net carbon source (Gitay *et al.*, 2001). Adverse impacts were projected for subsistence species like marine birds, seals, polar bears, tundra birds and tundra ungulates (Gitay *et al.*, 2001).

Impacts: Global warming is projected to be most pronounced at high latitudes (WG I, Chapters 10,11 - Phoenix and Lee, 2004). Ongoing rapid climatic changes will introduce poleward forcing of climatically near-equilibrium tundra at unprecedented rates (Velichko, 2002), causing largely lagged and critical responses in its slow growing plant communities (Camill and Clark, 2000; Velichko *et al.*, 2004; Chapin *et al.*, 2000; Callaghan *et al.*, 2004a; Callaghan *et al.*, 2004c): via (a) novel thermal regimes will tend to drive edificators (biome-specific environment-forming plants important for autonomous adaptation including soil formation) outside their current local zonal distribution, putting them at a competitive disadvantage relative to species immigrating from South; (b) rates of change together with flat tundra topography require large migration rates which exceed the migrational capacity of the edificators (Callaghan *et al.*, 2005). Taiga encroachment from South into tundra, which could compensate for these detrimental effects, is very likely to lag these changes (see 4.4.5 – e.g. Callaghan *et al.*, 2004b).

The thermally-stable oceanic climate of the sub-Antarctic Marion Island (47ºS, 38ºE) appears to be changing, with a rise in annual mean surface air temperature of 1.2ºC between 1969 and 1999. Annual precipitation decreased more or less simultaneously, and the 1990s was the driest in the island's five decades with records (Smith, 2002). These changes may be linked to a shift in phase of the semiannual oscillation in the Southern Hemisphere after about 1980 (Rouault *et al.*, 2005). Climatic change will directly affect the indigenous biota of sub-Antarctic islands, particularly through interactions with introduced biota (Smith, 2002; Barnes *et al.*, 2006). Experimental droughting of the keystone cushion plant species *Azorella selago* on Marion Island revealed measurable negative impacts after only several months (Le Roux *et al.*, 2005).

Projections of vegetation changes in the northern Arctic suggest for ~2080 that 17.6% (14-23%) of the current polar desert (1960 estimates) will be replaced by tundra vegetation (Callaghan *et al.*, 2005). The BIOME4 model (Kaplan *et al.*, 2003) projects for the Canadian Arctic a wide zone of shrub tundra displacing dwarf shrub tundra. Models operating at the biome level ignore key individualistic responses of tundra species, including differential migration rates (Chapin and Shaver, 1985). Thus in reality, communities without present analog are likely to form. Experimental manipulations of air temperature at 11 locations across the tundra also show that tundra plant communities change substantially by shifts in species dominance, canopy height, and diversity (Walker *et al.*, 2006) and that cryptogams are particularly vulnerable (Cornelissen *et al.*, 2001; van Wijk *et al.*, 2004). A warming of 1 to 3°C caused a short-term diversity decrease, but generalisations are unwarranted because of insufficiently long experimentation (van Wijk *et al.*, 2004; Graglia *et al.*, 2001; Dormann and Woodin, 2002; Walker *et al.*, 2006).

Moisture supply influences substantially the state of permafrost – one of the most important components of the tundra landscape (Anisimov and Nelson, 1996; Anisimov *et al.*, 2002b; Anisimov *et al.*, 2002a). A combined increase in temperature, active layer depth, and moisture content in the upper ground layer will not only promote paludification (Crawford *et al.*, 2003) and thermokarst processes as well the dryness in the elevated elements of topography, but also influence ecosystem structures and functions (Velichko *et al.*, 2005). Increasing instability of the active layer brings about more extensive mixing and lateral shifting of the mineral matrix in the soil, causing stress for the plant root systems, slowing decomposition. Generally this will favour moisture-loving species (e.g. sedges), while the peatbog vegetation over permafrost could experience drier conditions (Camill, 2005).

Projections for animal populations are still scanty and expected effects are manifold and sometimes detrimental, sometimes beneficial for the impacted population: While summer food availability may increase for some vertebrates (Hinzman *et al.*, 2005), icing rise events at critical winter times may reduce abundance (Aanes *et al.*, 2002; Yoccoz and Ims, 1999). Tundra wetland habitat for migrant birds may dry progressively (Smith *et al.*, 2005; Hinzman *et al.*, 2005). Many species of Arctic breeding shorebirds and waterfowl are projected to undergo major population declines as their tundra habitat disappears (Table 4.2, Box 4.6). In contrast, northern range extension of more southern species is expected, e.g. moose and red fox (Callaghan *et al.*, 2005). Some new colonisers might achieve the character of "invasive" species with major impacts, such as the North American Mink (Neuvonen, 2004), but also the presently restricted populations of southern "weeds" that are likely to spread in a warmer climate (Forbes, 1995) may eventually lead to substantive carbon emissions (Sturm *et al.*, 2001). For arctic species such as the polar bear major risks of extinction are associated with the large decrease in the extent of the sea ice biome and the sea ice cover (Box 4.4).

Box 4.4: Polar bears – a species in peril?

Polar bears (*Ursus maritimus*) live throughout the ice-covered waters of the circumpolar Arctic and can wander thousands of kilometres an year. There are an estimated 20,000 to 25,000 polar bears worldwide (IUCN/SSC Polar Bear Specialist Group, in prep.), mostly inhabiting the annual sea ice

over the continental shelves and inter-island archipelagos. They are specialized predators of ice-breeding seals and are therefore dependent on sea ice for survival. Mother bears give birth to cubs and nurse them in dens in snow banks. They emerge in spring after having fasted for 5 to 7 months (Ramsay and Stirling, 1988) and are in great need of a nourishing meal, a ringed seal best hunted from the ice before it breaks up. Polar bears having continuous access to sea ice are able to hunt throughout the year. However, in areas where the sea ice melts completely each summer, polar bears are forced to spend several months on land in the tundra biome fasting on stored fat reserves until freeze-up.
Both anthropogenic and natural changes in the Arctic marine ecosystem threaten the welfare of polar bears. Many persistent organic pollutants have been found to bioaccumulate through the food chain and reach high levels in polar bears (Norstrom *et al.*, 1998). Recent studies suggest that these contaminants not only affect the bear's endocrine and immune systems (Bernhoft *et al.*, 2000; Skaare *et al.*, 2001; Lie *et al.*, 2004; Lie *et al.*, 2005) but may also affect subsequent reproductive success (Derocher *et al.*, 2003).

The greatest challenges facing polar bears relate to the effects of climatic warming (Stirling and Derocher, 1993; Stirling *et al.*, 1999; Derocher *et al.*, 2004), particularly when the projections of various climate and ice models that suggest greatly diminished sea ice cover and extended open-water seasons are considered. Breakup of the sea ice on western Hudson Bay, Canada is already about 3 weeks earlier than it was in the early 1970s, resulting in polar bears in this area coming ashore earlier with reduced fat reserves (a 15% decline in body condition), fasting for longer periods of time, and having reduced productivity (Stirling *et al.*, 1999). Preliminary estimates suggest that the Western Hudson Bay population has declined from 1200 bears in 1987 to fewer than 950 in 2004. Although these changes are specific to one subpopulation, we might reasonably expect similar impacts on other subpopulations of polar bears. In 2005, the IUCN Polar Bear Specialist Group concluded that the IUCN Red List classification of the polar bear should be upgraded from Least Concern to Vulnerable based on the likelihood of an overall decline in the size of the total population of more than 30% within the next 35 to 50 years. The U.S. Fish and Wildlife Service is also considering a petition to list the polar bear as a threatened species based in part on future risks tot he species population from climate change. The principal cause of this decline is climatic warming and its consequent negative affects on the sea ice habitat of polar bears. Reductions in sea ice will drastically shrink marine habitat for polar bears, ice-inhabiting seals and other animals (Hassol, 2004b). If sea ice declines according to some projections (cf. WG I Chapter 10, Figure 10.3.10) polar bears are pushed towards extinction. Similar consequences are facing other ice-dependent species, not only in the Arctic but also in the Antarctic (Chapter 1, Barbraud and Weimerskirch, 2001; Croxall *et al.*, 2002).

Changes in albedo associated with loss of snow cover, and invasion of low, snow-covered tundra vegetation by darker evergreen coniferous trees is very likely to decrease regional albedo significantly and lead to a warming effect that is greater than the cooling projected from the increased carbon uptake by advancing forests and shrubs (Betts, 2000; Sturm *et al.*, 2001). Process based models generally indicate a net carbon sequestration in the Arctic due to enhanced production exceeding decomposition increases (McGuire *et al.*, 2000; Sitch *et al.*, 2007). However, the potential for carbon sequestration varies from region to region (Callaghan *et al.*, 2005) and model uncertainties are high (Sitch *et al.*, 2007), since changes in hydrology, permafrost, insect pest outbreaks, fire and human impacts are poorly represented, yet can have large effects on the carbon balance. The projected changes may cause an increase in carbon uptake (Camill and Clark, 2000; McGuire *et al.*, 2000; Zavarzin and Kudeyarov, 2006), but also to increases in areas of mires, peatlands and waterlogged soils leading to greater methane emissions (Christensen *et al.*, 2004). Moreover, models of methane fluxes project dramatic increases in CH_4 emissions as soils warm (Sitch *et al.*, 2007), offsetting the possible overall carbon sink due to the great greenhouse warming potential of CH_4.

Adaptation costs and opportunities: There are no cost estimates available and adaptation costs are expected to be high (Symon *et al.*, 2005).

Key vulnerabilities: Despite an overall increased carbon uptake, changes in albedo and increased releases of methane will lead to positive climate radiative forcing through the Arctic region. Unique endemic biodiversity (e.g. polar bear, Box 4.4) as well as tundra dependent, non-native species like migratory species (e.g. waterfowl, Box 4.6, section 4.4.8) are put at major extinction risks with the concomitant threats to food security for indigenous peoples (e.g. Inuit).

Impacts summary as a function of ΔT:
- A MGT rise of ~1°C is expected to reduce the tundra area in Siberia and North America.
- 4°C polar bears at high risk of extinction

Implications for policy and sustainable development: Changes in the availability of traditional resources as well as changes in their accessibility are likely to add to the stresses on the livelihoods of Arctic residents arising already from socio-economic changes in globalisation and life styles (Hassol, 2004b). Subsistence activities, particularly associated with gathering natural resources, are important for maintaining healthy social relationships and cultural identity (Chapin *et al.*, 2005a).

4.4.7 Mountains

Characteristics: Mountain regions (~20% of all land) exhibit many climate types within short horizontal distances that correspond to widely-separated latitudinal belts. Consequently, although species richness decreases with elevation, mountain ecosystems feature high beta diversity and in many regions are of the species richest ecosystems (e.g. Moser *et al.*, 2005; Spehn and Körner, 2005).

Goods and services: Mountain ecosystem services such as water purification and climate regulation extend beyond their geographical boundaries and affect all continental mainlands (e.g. Woodwell, 2004). Local key services allow inhabitability of mountain areas, e.g. through slope stabilisation or protec.tion from natural disasters, provide many goods for subsistent livelihoods, and are home to many indigenous peoples. They serve also increasingly as refuges for many endemic species and are attractive to recreational activities and tourism due to their relative remoteness.

Key vulnerabilities as from TAR: Shortened snow melt season leading to rapid water release and low elevation floods may cause water shortage during growing season, but these impacts may be dominated by ecosystem degradation pressures such as land-use changes, overgrazing, trampling, pollution, vegetation destabilization, and soil losses, in particular in highly diverse regions such as Caucasus and Himalayas (Gitay *et al.*, 2001). While adaptive capacities are generally considered limited, high vulnerability is attributed to many alpine biota with their high levels of endemism.

Impacts: Because temperature decreases with altitude by 5-10°C/km, a first-order approximation regarding the response of vegetation to climate change is that species will migrate upwards to find climatic conditions in tomorrow's climate which are similar to today (e.g., MacArthur, 1972; Beniston, 2000), leading to a loss of the coolest climatic zones at the mountain peaks and upslope shifts of vegetation belts (Gitay *et al.*, 2001; Penuelas and Boada, 2003). Because mountain tops are smaller than their bases, upward shifting vegetation belts are reduced to increasingly smaller areas, which may genetically deteriorate species and make them more vulnerable to other environmental pressures such as pollution (Peters and Darling, 1985; Bortenschlager, 1993). However, despite the relative short distances to be covered, for many endemic species upward migration is constrained by genetically fixed climatic tolerances, and in general a reshuffling of competition pressures due to particular species-individualistic responses through varying longevities and survival rates drawing from a high degree of evolutionary specialisation to the harsh mountain climate (e.g. Gottfried *et al.*, 1999; Theurillat *et al.*, 1998; Theurillat and Guisan, 2001; Klanderud, 2005; Klanderud and Totland, 2005; Dullinger *et al.*, 2005; Huelber *et al.*, 2006), including effects from invading alien species (e.g. Dukes and Mooney, 1999; Mack *et al.*, 2000). In contrast to the short distance upward shifts, mountain ridges also represent considerable obstacles to dispersal for many species as evidenced by many paleoecological and modelling studies (e.g. Foster, 2001; Lischke *et al.*, 2002; Neilson *et al.*, 2005; Pounds *et al.*, 2006).

Treelines representing the interface between subalpine forests and low-growing alpine meadows are partly controlled by carbon balance (Körner, 1999; Monson *et al.*, 2002), but according to recent findings surpsisingly strongly by temperature, in particular soil temperature, which moderates the growth rate of all small mountain plants (worldwide climatic treelines are characterized by seasonal mean ground temperature of 6.7±1.6°C (95% confidence interval) Körner, 1998; Grace *et al.*, 2002; Korner and Paulsen, 2004; Millar *et al.*, 2004; Zha *et al.*, 2005; Lara *et al.*, 2005). In many mountains the treeline is located below its potential climatic limit because of grazing, in case of the European Alps century-old, or disturbances such as wind or fire. In other regions such as the Himalayas, deforestation of past decades has transformed much of the environment and fragmented ecosystems (Becker and Bugmann, 2001). Although temperature control may well be dominant at equilibrium with climate, ability of tree populations to follow temperature have been challenged by recent findings (Shiyatov, 2003; Wilmking *et al.*, 2004; Dullinger *et al.*, 2004).

Where warmer and drier conditions are projected, mountain vegetation is expected to suffer from increased evapo-transpiration (Ogaya *et al.*, 2003; Jasper *et al.*, 2004; Stampfli and Zeiter, 2004; Rebetez and Dobbertin, 2004; Zierl and Bugmann, 2005; Jolly *et al.*, 2005; Pederson *et al.*, 2006), which has been projected to lead to subalpine forest dieback for continental climata in the interior of mountain ranges (e.g. Fischlin and Gyalistras, 1997; Lischke *et al.*, 1998; Lexer *et al.*, 2000; Bugmann *et al.*, 2005) or areas under the influence of a Mediterranean climate. Even in humid tropical regions, plants and animals have been shown to be sensitive to water stress on mountains such as Mt. Kinabalu in the Malaysian part of Borneo (Kitayama, 1996) or Costa Rica (Still *et al.*, 1999).

The duration and depth of snow cover, often correlated with mean temperature and precipitation (Keller *et al.*, 2005; Monson *et al.*, 2006), is a key factor in many alpine ecosystems (Körner, 1999; Daimaru and Taoda, 2004). Missing snow cover exposes plants and animals to frost and influences water supply in spring (Keller *et al.*, 2005). If animal movements are disrupted by changing snow patters, as has been found in Colorado (Inouye *et al.*, 2000), increased wildlife mortality may result through a mismatch between wildlife and environment. Warming caused by increased precipitation lead at high altitudes to higher snowfall, so that earlier arriving altitudinal migrants are confronted with delayed snowmelt (Inouye *et al.*, 2000).

In the harsh mountain climate disturbances such as avalanches, rock fall, fire, wind, and herbivore damage interact and are strongly dependent from climate (e.g. Whitlock *et al.*, 2003; Beniston and Stephenson, 2004; Carroll *et al.*, 2004; Cairns and Moen, 2004; Hodar and Zamora, 2004; Schumacher *et al.*, 2004; Schoennagel *et al.*, 2004; Pierce *et al.*, 2004; Kajimoto *et al.*, 2004). These effects are often detrimental, prevent recruitment which is crucial during phases needing adaptation, and are exacerbated by human land-use and other anthropogenic pressures (e.g. Lawton *et al.*, 2001; Dirnbock *et al.*, 2003; Huber *et al.*, 2005).

The increasing interest in analysing climatic change sensitive ecotones such as the treeline in mountains (e.g. Camarero *et al.*, 2000; Walther *et al.*, 2001; Diaz, 2003; Sanz-Elorza *et al.*, 2003) has shown that several mountain-restricted species will exhibit population loss (e.g. Beever *et al.*, 2003; Florenzano, 2004). Most vulnerable ecotone species are those that are genetically poorly adapted to rapid environmental change, reproduce slowly, disperse poorly, and which are isolated or are highly specialized, because of their high sensitivity to seemingly minor stresses (McNeely, 1990). Recent findings for Europe, despite the spatially coarse analysis, indicate that mountain species are disproportionately sensitive to climate change (~60% species loss Thuiller *et al.*, 2005). Moreover, if in addition to climate change also human pressures exert impacts on mountain biota, substantial biodiversity losses are to be expected (Pounds *et al.*, 1999; Lawton *et al.*, 2001; Pounds, 2001; Pauli *et al.*, 2001; Pauli *et al.*, 2003; Solorzano *et al.*, 2003; Halloy and Mark, 2003; 30% loss of birds Peterson, 2003; Pounds and Puschendorf, 2004; Pounds *et al.*, 2006).

Adaptation costs and opportunities: No estimates available.

Key vulnerabilities: Disproportional high risk of extinction for many endemic species in diverse mountain ecosystems such as the montane cloud forests or forests in other tropical regions on several continents (Williams *et al.*, 2003; Pounds and Puschendorf, 2004; Andreone *et al.*, 2005; Pounds *et al.*, 2006) or wherever endemic species loose their mountain habitat that is shrinking due to warming (Pauli *et al.*, 2003; Thuiller *et al.*, 2005)

Impacts summary as a function of ΔT:

- > 2°C in highly diverse Australian wet tropics cause complete loss of core environments with high extinction risks for endemic species (Williams *et al.*, 2003)
- > 3°C profound changes in all biota expected (Theurillat and Guisan, 2001)

4.4.8 Wetlands, Freshwater lakes and rivers

Characteristics: Inland aquatic ecosystems vary greatly in hydrological characteristics and global distribution. Most of the mighty rivers drain tropical and subtropical lands, and several of them pass through highly arid regions. A majority of natural freshwater lakes are located in the higher latitudes, whereas most of the artificial lakes occur in mid- and lower latitudes. Numerous saline lakes occur at altitudes up to 5000 m a.s.l., especially in the Himalaya and Tibet. The majority of natural wetlands (peatlands) is in the boreal region but most managed wetlands (rice paddies) are in the tropics and subtropics. Global estimates of area under rivers, lakes and wetlands vary greatly depending upon definition (Finlayson *et al.*, 2005). This chapter follows the TAR in considering 'wetlands' as distinct from rivers and lakes. Wetlands encompass a most heterogenous spectrum of habitats along the hydrological and nutrient gradients and all key processes, including goods and services provided, depend on the catchment level hydrology. Inland waters are also subject to many pressures due to their position downstream from many human activities.

Goods and services: Aquatic ecosystems provide a wide range of goods and services (Gitay *et al.*, 2001; Finlayson *et al.*, 2005), which include water supply and waste assimilation. Rivers transport water and nutrients from the land to the oceans and provide crucial buffering capacity during drought spells by being fed from mountain springs and glaciers (e.g. European summer 2003). The endorheic lakes serve as sediment and carbon sinks (Cohen, 2003) and hereby provide crucial repositories of information on past climate changes. Wetlands are often biodiversity 'hotspots' (Reid *et al.*, 2005) and play a major role for climate change through both carbon sequestration and methane emissions (Finlayson *et al.*, 2005).

Key vulnerabilities as from TAR: Gitay *et al*. (2001) described some inland aquatic ecosystems (arctic, subarctic ombrothropic bog communities on permafrost, depressional wetlands with small catchments, drained or otherwise converted peatlands) as most vulnerable to climate change, and indicated the limits to adaptations due to the dependence on water availability controlled by outside factors.

Impacts: The climate change impacts on inland aquatic ecosystems will range from the direct effects of the rise in temperature and CO_2 concentration to indirect effects through alterations in the hydrology resulting from the changes in the regional or global precipitation regimes and the melting of glaciers and ice cover (e.g. Cubasch *et al.*, 2001 chapter 3, WGI chapters 4, 10).

Studies since TAR have confirmed and strengthened the earlier conclusions that the rising temperature will lower the water quality in lakes through a fall in hypolimnetic oxygen concentrations, release of P from the sediments, increased thermal stability, altered mixing patterns (McKee *et al.*, 2003; Verburg *et al.*, 2003; Winder and Schindler, 2004; Jankowski *et al.*, 2006). It will affect the microorganisms and benthic invertebrates (Kling *et al.*, 2003). The distribution range of many species of fish (Lake *et al.*, 2000; Poff *et al.*, 2002; Kling *et al.*, 2003), invertebrates, invasive biota and waterfowl will shift northwards (Moss *et al.*, 2003; Zalakevicius and Svazas, 2005) while some will become extinct (Jackson and Mandrak, 2002; Chu *et al.*, 2005). Major changes will occur in the species composition, seasonality and production of planktonic communities (e.g., increase in nuisance bluegreen algal blooms) and their food web interactions (Gerten and Adrian, 2002; Kling *et al.*, 2003; Winder and Schindler, 2004). Studies along an altitudinal gradient in Sweden show that NPP can increase by an order of magnitude by a 6° C air temperature increase(Karlsson *et al.*, 2005). Tropical lakes may however respond by a decrease in NPP and a decline in fish yields (e.g. due to last century warming reductions in Lake Tanganyika: 20% NPP, 30% fish yields O'Reilly *et al.*, 2003). Higher CO_2 levels will generally increase NPP, whereas in the tropics this may also stimulate methane fluxes, particularly from paddy fields, thereby negating the positive effects (Ziska *et al.*, 1998; Freeman *et al.*, 2004). Boreal peatlands will be affected most by warming and increased winter precipitation as the species composition of both plant and animal communities will change significantly (Keller *et al.*, 2004; Weltzin *et al.*, 2003; Weltzin *et al.*, 2001; Weltzin *et al.*, 2000; Berendse *et al.*, 2001). Numerous Arctic lakes will disappear with a 2-3°C temperature rise (Smith *et al.*, 2005; Symon *et al.*, 2005). The seasonal migration patterns and routes of many wetland species will change considerably and their survival will be reduced up to the risk of extinction (Reid *et al.*, 2005; Finlayson *et al.*, 2005; Inkley *et al.*, 2004; Zalakevicius and Svazas, 2005).

Small increases in the variability in precipitation regimes suffice to significantly impact wetland plants and animals at different stages of their life cycle (Keddy, 2000). In monsoonal regions increased variability risks to diminish wetland biodiversity and prolonged dry periods promote terrestrialization of wetlands as witnessed in Keoladeo National Park (India Gopal and Chauhan, 2001; Chauhan and Gopal, 2001). In dryland wetlands, changes in the precipitation regimes may cause the loss of biodiversity (Bauder, 2005). An increase or decrease in freshwater flows will affect the coastal wetlands (chapter 6) by altering salinity, sediment inputs and nutrients (Schallenberg *et al.*, 2001; Flöder and Burns, 2004).

Adaptation costs and opportunities: The climate change will increase significantly the costs of treatment of water and possibly, the control of invasive species. It provides opportunities for developing adaptive management strategies, technologies that ensure environmental flows for aquatic ecosystem goods and services, and for improving various biodiversity related policies and conventions (Boere and Taylor, 2004).

Key vulnerabilities: vulnerability varies between different geographical regions (Van Dam *et al.*, 2002) but both the water quality and ecosystem goods and services will generally deteriorate. Their close relationship to hard and costly to control hydrological regimes and their often cross-national dependence on catchments leave little scope for adaptation.

Impacts summary as a function of ΔT: Currently available data are mostly inadequate to specify impacts as a function of temperature change. A 2-3°C temperature rise can increase the DOC release by up to 700% (Frey and Smith, 2005)

Implications for policy and sustainable development: Anthropogenic impacts on aquatic ecosystems and their terrestrial catchments complicate the climate change impacts (Hartig *et al.*, 2002; Kabat *et al.*, 2004; Pyke and Marty, 2005). Increasing demand for water, coupled with decreased supply in some regions (de Wit and Stankiewicz, 2006) in the wake of uncertainties of precipitation will threaten the inland aquatic ecosystems directly. The future of the aquatic ecosystems will therefore depend upon the adoption of integrated water management strategies at the continental scale that adapt to changing availability of water resources.

4.4.9 Oceans, shallow seas and their ecosystems

Characteristics: Oceans cover over 71% of the earth's surface area, they extend from polar to tropical regions and due to this significant coverage and depth (mean is 4000m) comprise about 98% of the Earth's biosphere (14 billion km^3). They are a massive reservoir of carbon and harbour a great biodiversity throughout their depths, both in the pelagic and benthic realms, and at their interface with land. For this reason they support a diverse range of ecosystems from highly productive (e.g. upwelling regions) to those with low productivity (e.g. oceanic gyres). Nearly half of global primary production is carried out by phytoplankton and is the basis of the marine food web (Field *et al.*, 1998). Ocean primary productivity depends on sunlight and nutrients supplied from deep waters (Sarmiento *et al.*, 2004a).

Goods and services: Marine ecosystems provide important and valuable goods and services (e.g. fisheries and aquaculture, provision of energy, recreation and tourism, CO_2 draw down and climate stabilization, decomposition of organic matter and regeneration of nutrients, coastal protection and they harbour an extensive biodiversity) many of which are critical to the functioning of the Earth system (Chapter 5, Costanza *et al.*, 1997; Hassan *et al.*, 2005 Table 18.2, p. 79; McCarthy *et al.*, 2001 Sections 6.3.2, 6.3.4, 6.3.5, 6.4.5 and 6.4.6). Coastal zones, particularly low lying areas, and the highly valuable local and global socioeconomic services they provide (e.g. agricultural land, human settlements and associated infrastructure and industry, aquaculture and fisheries and freshwater supply) are particularly vulnerable to climate change (Hassan *et al.*, 2005 Section 19.3.2, Table 19.2, p. 531, p. 676; McCarthy *et al.*, 2001 Section 6.5, p. 362).

Key vulnerabilities as from TAR: Impacts of high atmospheric CO_2 on lower surface ocean pH and carbonate ions were overlooked in TAR. Coral reefs, cold water corals, and ecosystems (e.g. Southern Ocean) where aragonite will decline or become undersaturated and where calcarious organisms (e.g. pteropods) play an important role will become vulnerable this century (reviewed by Raven *et al.*, 2005). Synergistic impacts of higher seawater temperatures and declining carbonate make these ecosystems even more vulnerable (e.g. Raven *et al.*, 2005; Turley *et al.*, 2006 Box 4.5). Marginal sea ice and surrounding ecosystems are vulnerable to warming, particularly in the Northern Hemisphere (Sarmiento *et al.*, 2004b).

Box 4.5: Coral reefs – are coral reefs endangered by climate change?

Reefs are habitat for about a quarter of marine species and are the most diverse among marine ecosystems (Roberts *et al.*, 2002; Buddemeier *et al.*, 2004). They underpin local shore protection, fisheries, tourism (Chapter 6 Hoegh-Guldberg *et al.*, 2000; Hoegh-Guldberg, 2004; Hoegh-Guldberg, 2005; Cesar *et al.*, 2003; Willig *et al.*, 2003), and though supplying only about 2-5% of the global fisheries harvest, comprise a critical subsistence protein source (Pauly *et al.*, 2002).

Corals are affected by rising atmospheric CO_2 concentrations (WG I Box 7.3 Orr *et al.*, 2005; Raven *et al.*, 2005) and by warming of ocean surface waters (Box 6.1 Reynaud *et al.*, 2003; McNeil *et al.*, 2004;

McWilliams *et al.*, 2005) leading to declining calcification and bleaching: Experiments at expected aragonite concentrations demonstrated a reduction in coral calcification (Langdon *et al.*, 2003; Marubini *et al.*, 2001; Hallock, 2005), coral skeleton weakening (Marubini *et al.*, 2003) and strong temperature dependence (Reynaud *et al.*, 2003). Oceanic pH projections go lower and at a greater rate than known from the past 20 million years (Turley *et al.*, 2006; Raven *et al.*, 2005; Caldeira and Wickett, 2003). Doubling CO_2 will reduce calcification in aragonitic corals by 20%-60% (Kleypas *et al.*, 1999; Kleypas and Langdon, 2002; Reynaud *et al.*, 2003; Raven *et al.*, 2005). By 2070 many reefs could reach marginal aragonite saturation states (Feely *et al.*, 2004; Orr *et al.*, 2005), resulting in reduced coral cover and physically and biologically more erodible reef frameworks (Kleypas *et al.*, 2001; Guinotte *et al.*, 2003). Many studies incontrovertibly link coral bleaching to warmer SSTs (e.g. McWilliams *et al.*, 2005) and mass bleaching and coral mortality often results beyond key temperature thresholds (see Box 6.1). Near-annual exceedance of current bleaching thresholds are projected for several sites globally by GCMs around 2040, and in some places even by 2020 (Hoegh-Guldberg, 1999; Sheppard, 2003). After bleaching, algae quickly colonise dead corals, possibly inhibiting later coral recruitment (e.g. McClanahan *et al.*, 2001; Szmant, 2001; Gardner *et al.*, 2003; Jompa and McCook, 2003). Modelling predicts a switch to algal dominance in 2030 to 2050 (Wooldridge *et al.*, 2005; Langmead and Sheppard, 2007).

Adaptation potential (Hughes *et al.*, 2003) by reef organisms requires further experimental and applied study (Coles and Brown, 2003; Hughes *et al.*, 2003). Natural adaptive shifts to symbionts with +2°C resistance will delay demise of reef facies to roughly 2100 (Sheppard, 2003), rather than mid-century (Hoegh-Guldberg, 2005). Around 30% of warm water corals have disappeared in the last 20 years (Hoegh-Guldberg, 2005) due largely to increasing higher SST frequency (Hoegh-Guldberg, 1999). In some regions, such as the Caribbean, coral losses have been estimated at 80% (Gardner *et al.*, 2003). Coral migration to higher latitudes with more optimal SST is unlikely, due both to latitudinally decreasing aragonite concentrations and projected atmospheric CO_2 increases (Kleypas *et al.*, 2001; Guinotte *et al.*, 2003; Orr *et al.*, 2005; Raven *et al.*, 2005). Elevated SST and decreasing aragonite have a complex synergy (McNeil *et al.*, 2004; Kleypas *et al.*, 2005; Reynaud *et al.*, 2003) but could

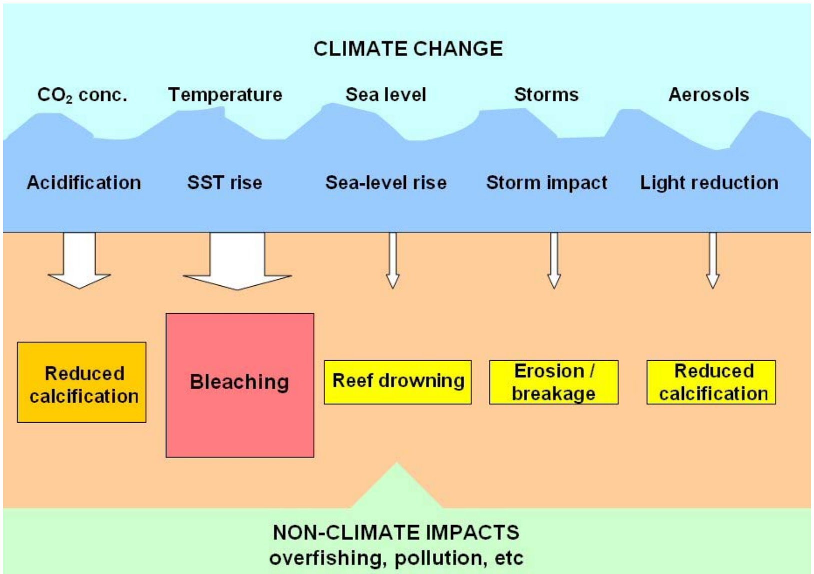

Fig. 4.3: *Impacts of climate change and non-climate impacts on coral reefs (modified from Kleypas and Langdon, 2002). The box sizes are scaled relative to literature on climate impacts on reefs (Bleaching, Box 6.1; non-climate impacts Chapter 16; case study of the World Heritage site, the Great Barrier Reef Box 11.1).*

produce major coral reef changes (Hoegh-Guldberg, 2005; Guinotte *et al.*, 2003). Corals could become rare on tropical and sub tropical reefs by 2050 (at 2-3 x CO2 Raven *et al.*, 2005; Hoegh-Guldberg, 2005; Kleypas and Langdon, 2002). Other climate change (sea-level rise, storm impact, aerosols) and non-climate factors (over-fishing, pollution, nutrient and sediment load, Boxes 6.2, 11.1, and chapter 16) add multiple impacts on coral reefs (Fig. 4.3), increasing vulnerability and reducing resilience to climate change (Kleypas and Langdon, 2002; Buddemeier *et al.*, 2004; Hallock, 2005; Cole, 2003; Koop *et al.*, 2001).

Impacts: Climate change can impact marine ecosystems through ocean warming (Wang *et al.*, 2004b) by increasing thermal stratification and reducing upwelling (Cox *et al.*, 2000; Sarmiento *et al.*, 2004a), sea level rise (Houghton *et al.*, 2001), increase in wave height and frequency (Monahan *et al.*, 2000; Wang *et al.*, 2004b), loss of sea ice (Sarmiento *et al.*, 2004b) and decreases in the pH and carbonate ion concentration of the surface oceans (Caldeira and Wickett, 2003; Feely *et al.*, 2004; Sabine *et al.*, 2004; Raven *et al.*, 2005).

Coupled physical/biogeochemical models predict a net ~5% decrease in global phytoplankton productivity (-20% in the tropics and +30% at high latitudes) and ~6% decrease in export production under 2 x CO_2 due to increased oceanic thermal stratification and reduced upwelling of nutrients (Cox *et al.*, 2000). Theoretically, nutrient speciation could also be influenced by the lower pH expected this century (Zeebe and Wolf-Gladrow, 2001; Raven *et al.*, 2005). Decreases in both upwelling and formation of deep water and increased stratification of the upper ocean will reduce the input of essential nutrients into the sunlit regions of oceans and reduce productivity (Sarmiento *et al.*, 2004a; Cox *et al.*, 2000; Loukos *et al.*, 2003; Lehodey *et al.*, 2003).

Projections of ocean biological response to climate warming by 2050 show contraction of the highly productive marginal sea ice biome by 42% and 17% in Northern and Southern Hemispheres under IS92a (Sarmiento *et al.*, 2004b). The sea-ice biome accounts for a large proportion of primary production in polar waters and supports a substantial food web. As timing of the spring phytoplankton bloom is linked to the sea ice edge, loss of sea ice (Walsh and Timlin, 2003) and large reductions of the total primary production in the Northern Hemisphere marginal sea ice biome in the Northern Hemisphere (Behrenfeld and Falkowski, 1997; Marra *et al.*, 2003) would have strong effects, for example, on the productivity of the Bering Sea (Stabeno *et al.*, 2001). Expansion of the low productivity permanently stratified subtropical gyre biome by 4.0% (Northern) and 9.4% (Southern Hemisphere) and the subpolar gyre biome by 16% (Northern) and 7% (Southern Hemisphere) and contraction of the seasonally stratified subtropical gyre by 11% in both hemispheres are also predicted by 2050 due to climate warming under IS92a (Sarmiento *et al.*, 2004b). If the predictions of reduced productivity and reduction and expansion of key biomes are accurate then it seems likely that marine ecosystems will respond but the extent of this is difficult to predict based on current understandings (Sarmiento *et al.*, 1998).

Major changes to planktonic and benthic community composition and productivity have been observed in North Sea since 1955 (Clark and Frid, 2001) and changes since the mid-1980s may have reduced the survival of young cod (Beaugrand *et al.*, 2003). Elevated temperatures increased mortality of winter flounder eggs and larvae (Keller and Klein-Macphee, 2000) and a 2^{o}C rise in SST would result in removal of Antarctic bivalves and limpets from the Southern Ocean (Peck *et al.*, 2004). Tuna populations may spread towards presently temperate regions, based on predicted warming of surface water and increasing primary production at mid and high latitudes (Loukos *et al.*, 2003). Warming El Niño events have had a positive impact on skipjack populations in the Pacific Ocean (Lehodey *et al.*, 2003).

CO_2 emitted to the atmosphere by human activities has been absorbed by the oceans, making them more acidic. Surface ocean pH has already decreased by 0.1 unit (equivalent to a 30% increase in hydrogen ion concentration) and is predicted to decreases by a further 0.3-0.4 units by 2100 (Caldeira and Wickett, 2003). This may impact a wide range of organisms and ecosystems (e.g. Box 4.5, reviewed by Raven *et al.*, 2005) including juvenile planktonic, as well as adult, forms of benthic calcifying organisms (e.g.

echinoderms, gastropods and shellfish) and impact recruitment (reviewed by Turley *et al.*, 2006). Aragonite undersaturation is predicted to occur in polar and subpolar surface waters and the Southern Ocean will be undersaturated by 2100 (Orr *et al.*, 2005). Organisms using aragonite to make their shells (e.g. pteropods) will be at risk and this will threaten ecosystems such as the Southern Ocean in which they play a dominant role in the foodweb and carbon cycling (Orr *et al.*, 2005). Cold-water coral ecosystems, have been found in almost all the world's oceans and their aerial coverage could equal or exceed that of warm-water coral reefs (Freiwald *et al.*, 2004; Guinotte *et al.*, 2006). They harbour a distinct and rich ecosystem, provide habitats and nursery grounds for a variety of species, including commercial fish and numerous new species and previously thought to be extinct species (Raven *et al.*, 2005). These geologically ancient, long-lived, slow growing and fragile reefs will suffer reduced calcification rates and as the aragonite saturation horizon moves towards the ocean surface large parts of the oceans will be uninhabitable to them by 2100 (Feely *et al.*, 2004; Orr *et al.*, 2005; Guinotte *et al.*, 2006; Raven *et al.*, 2005). Since cold-water corals do not have symbiotic algae but depend on extracting food particles sinking from surface waters or carried by ocean currents they are also vulnerable to changes to ocean currents, primary productivity and flux of food particles (Guinotte *et al.*, 2006). Warm-water coral reefs are also sensitive to multiple impacts including increased sea surface temperature (SST) and decreasing aragonite concentrations within this century (Box 4.5).

Adaptation costs and opportunities: Increasing global temperatures would shift species' geographic ranges to higher latitudes or tidal heights due to changes in sea-level (time of exposure), and air and water temperature, but could also cause localised extinctions at "hot spots" (Helmuth *et al.*, 2002) but abilities of calcifying organisms to adapt to decreasing carbonate ions by changing their geographical distribution or physiology are of concern (Box 4.5). Future reduction of CO_2 emissions is the only method of reducing impacts from ocean acidification (Raven *et al.*, 2005). Protection and/or adaptation of climate change impacts on coastal zones, particularly low lying areas, and the highly valuable local and global socioeconomic services will be very costly economically, socially and culturally (McCarthy *et al.*, 2001 6.5, p.362; Hassan *et al.*, 2005 p. 677).

Key vulnerabilities: Known key vulnerable ecosystems are warm-water coral reefs (Box 4.5), cold-water corals, the Southern Ocean and marginal sea ice ecosystems.

Impacts summary as a function of ΔT:

- 2 x CO_2: net ~5% decrease in global phytoplankton productivity (-20% in the tropics and +30% at high latitudes Cox *et al.*, 2000).
- 2 x CO_2: net ~6% decrease in export production (Cox *et al.*, 2000).
- 2050: contraction of the highly productive marginal sea ice biome by 42% and 17% in Northern and Southern Hemispheres (Sarmiento *et al.*, 2004b).
- 2050: expansion of the low productivity permanently stratified subtropical gyre biome by 4.0% (Northern) and 9.4% (Southern Hemisphere) and the subpolar gyre biome by 16% (Northern) and 7% (Southern Hemisphere Sarmiento *et al.*, 2004b).
- 2050: contraction of the seasonally stratified subtropical gyre biome by 11% in both hemispheres (Sarmiento *et al.*, 2004b).
- 2^oC (SST): loss of Antarctic bivalves and limpets from the Southern Ocean (Peck *et al.*, 2004).
- ~1^oC (SST): Major changes to planktonic and benthic community composition and productivity in North Sea (Clark and Frid, 2001; Beaugrand *et al.*, 2003).
- ~1^oC (SST): reduced survival of young cod in North Sea (Beaugrand *et al.*, 2003).
- ~1^oC (SST): increasing loss of warm-water coral reefs due to bleaching (Hoegh-Guldberg, 2005).
- ~2^oC (SST): loss of warm-water corals globally – any adaptive symbionts unlikely to function (Sheppard, 2003).
- 2 x CO_2: reduced calcification in warm water aragonitic corals by 20%-60% (Raven *et al.*, 2005; Hoegh-Guldberg, 2005; Kleypas and Langdon, 2002).
- 2100: 70% reduction in cold-water aragonitic corals (Guinotte *et al.*, 2006).

- 2100: Loss of aragonitic pteropods from Southern Ocean (Feely *et al.*, 2004; Orr *et al.*, 2005).

Impacts for policy and sustainable development: Coral reef impacts will be significant to sustainability of the Small Island Nations and to fisheries and tourisms of nations adjacent to reef systems. Loss of sea ice and reduced productivity in surrounding waters will impact fisheries and biodiversity. Reduction or contraction of ocean biomes will result in redistribution of ocean productivity which will impact fisheries policies and sustainable development. Ocean uptake of anthropogenic CO_2 may concern conventions for the protection of the Earth's seas (e.g. The London Convention, OSPAR). Marine ecosystems are very important in regulating the earth life support system and climate change impacts on them will be very costly economically, socially and culturally (McCarthy *et al.*, 2001 6.5, p.362; Hassan *et al.*, 2005 p. 677). The only way of regulating the impacts of ocean acidification is substantial reductions in CO_2 emissions (Raven *et al.*, 2005).

4.4.10 Cross-biome impacts

This section highlights issues that cut across biomes, such as large-scale geographic shifts of vegetation (Fig. 4.4) or animal migration patterns (e.g. Box 4.4, Box 4.6), and changes in land use and aquatic systems.

Boreal forest and Arctic tundra ecosystems are projected to experience increased growth as a consequence of longer and warmer growing seasons (Lucht *et al.*, 2002 see also Fig. 4.4). Woody boreal vegetation is expected to expand to higher latitudes and higher elevations at the expense of tundra (Grace *et al.*, 2002; Kaplan *et al.*, 2003; Gerber *et al.*, 2004). At the southern ecotone to the grasslands of the continental interiors, increased drought stress is projected to cause a recession of boreal forest due to increased vulnerability to drought, insects and fires (Bachelet *et al.*, 2001; Scholze *et al.*, 2007), and a lower rate of sapling survival (Hogg and Schwarz, 1997). This forest die-back could be partially mitigated by concurrent CO2-induced enhanced water use efficiency (Gerten *et al.*, 2005), small regional increases in precipitation and an increased depth of permafrost thawing. It is uncertain whether peak summer heat stress on boreal tree species could potentially cause regional transitions to grassland where continental winter climate remains too cold for temperate forest species to succeed (Gerber *et al.*, 2004; Scholze *et al.*, 2007). Vegetation change in the lower to mid latitudes is uncertain because transitions between tropical desert and woody vegetation covers are particularly difficult to forecast. Climate models disagree in pattern and magnitude of projected changes in atmospheric circulation and climate variability, particularly for precipitation (e.g. with respect to the Indian and West African monsoons). For the Sahel and other semi-arid regions, increasing drought is predicted by some models (Held *et al.*, 2005), while increased water use efficiency is projected to cause more greening, though potentially associated with more frequent fires, in others (Bachelet *et al.*, 2003; Woodward and Lomas, 2004b; Schaphoff *et al.*, 2006; Ni *et al.*, 2006). Substantial drought stress in the Mediterranean region is reasonably certain (Hayhoe *et al.*, 2004; Schroter *et al.*, 2005). In savannahs, woody encroachment is projected to be a consequence of enhanced water use efficiency and increased precipitation in some regions (Bachelet *et al.*, 2001; Schaphoff *et al.*, 2006; Ni *et al.*, 2006). A general increase of deciduous over evergreen vegetation is predicted at all latitudes, although the forests in both the eastern U.S. and eastern Asia appear to be sensitive to drought stress and decline under some scenarios (Bachelet *et al.*, 2001; Scholze *et al.*, 2007; Gerten *et al.*, 2005). Non-woody C3 vegetation is projected to increase over C4 vegetation due to carbon fertilisation despite the competitive advantage of C4 plants at higher temperatures (Collatz *et al.*, 1998; Gerten *et al.*, 2005). Tropical ecosystems are expected to change particularly in the Amazon, where a subset of GCMs shows strong to moderate reductions in precipitation with the consequence of transitions of evergreen tropical forest to raingreen forest or grasslands (Cox *et al.*, 2004; Cramer *et al.*, 2004; Woodward and Lomas, 2004b). However, representations of tropical succession remains underdeveloped in current models. The global land biosphere is projected to loose carbon beyond temperature increases of 3 degrees (Gerber *et al.*, 2004), mainly from temperate and boreal soils, with vegetation carbon declining beyond temperature increases above 5 degrees (Gerber *et al.*, 2004). Carbon sinks persist mainly in the Arctic and in savannah grasslands (Woodward and Lomas, 2004b; Schaphoff *et al.*, 2006). However, there is large variability between the projections of different vegetation (Cramer *et al.*, 2001) and climate (Schaphoff *et al.*, 2006) models for a given emission scenario (Fig. 4.4).

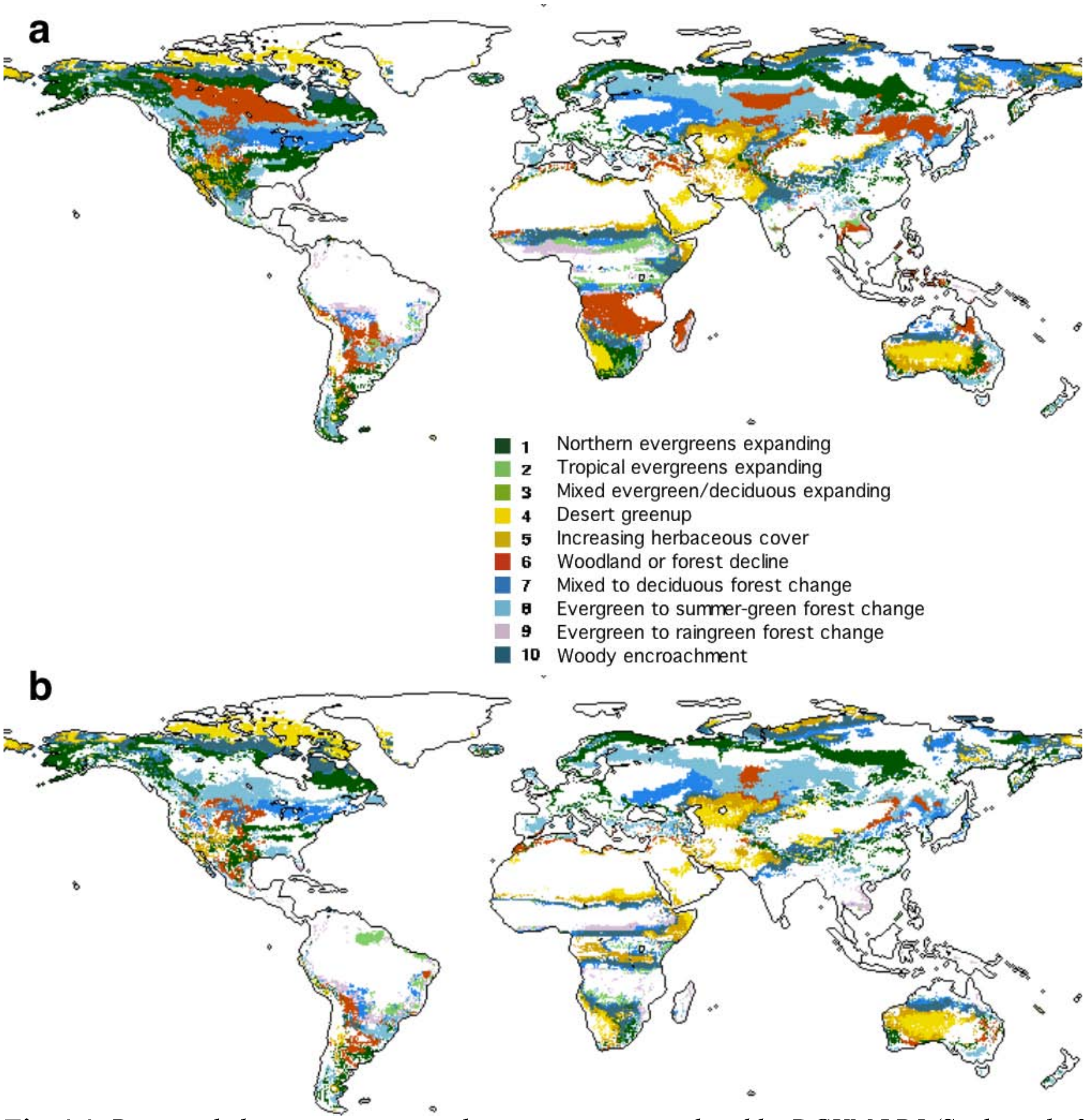

Fig. 4.4: *Projected changes in terrestrial ecosystems as simulated by DGVM LPJ (Sitch et al., 2003; Gerten et al., 2004) for two IPCC SRES emission scenarios (Nakicenovic et al., 2000) forcing two climate models: a) HadCM3 A2, b) ECHAM5 B1 (Schaphoff et al., 2006 - see Fig. 4.2 for explanations and Table 4.3).*

Most global scenario studies agree that land use change will be the dominant driver of terrestrial biodiversity loss, before changes in climate and other drivers such as nitrogen deposition (Jenkins, 2003; Carpenter *et al.*, 2005; Sala *et al.*, 2000; Scharlemann *et al.*, 2004; Thomas *et al.*, 2004a; UNEP, 2002) through 2050 in many ecosystems (see below). In freshwater systems (World Commission on Dams, 2000) and oceans (Pauly *et al.*, 2002), extractive use has degraded biodiversity habitats, communities and foodwebs. The relative importance of these drivers varies across biomes (Sala *et al.*, 2000). Climate change is likely to be more important than land use change where the magnitude of projected climate change is greatest and human intervention is limited such as in the tundra, boreal, cool conifer forests and savannah biomes (Duraiappah *et al.*, 2005; Sala *et al.*, 2000). In South African Fynbos, climate change is projected to threaten more endemic plant species richness than land use change by 2020 (Bomhard *et al.*, 2005). All global studies project a significant reduction in native vegetation (principally forest) in non-industrialised countries and arid regions due to expansion of agricultural or urban land use driven principally by population growth, especially in Africa, South America and in South Asia where a reduction in native habitat will result in biodiversity loss (Carpenter *et al.*, 2005). Globally, biodiversity (represented by species richness and relative abundance) may decrease by 12-16% by 2050 (Duraiappah *et al.*, 2005) and are likely in virtually all biomes (Duraiappah *et al.*, 2005 Re105; Sala *et al.*, 2000), with tropical forest and woodland, savanna and warm mixed forest accounting for 80% of the species lost (~30,000 species) by 2050 (Duraiappah *et al.*, 2005). Biomes that have been subjected to large change in the past such as Mediterranean forests and temperate grasslands will be least affected by land use change over the next 50 years. Northern latitude countries may become increasingly important for biodiversity and species conservation as the ranges of species distributions move poleward in response to climate change (Berry *et al.*, 2006). Northern latitude countries are also sensitive to the effects of climate change on land use (especially agriculture) and these regions could support adaptation strategies to mitigate the negative effects of future climate and land use change. Biomes at the highest latitudes that have not already been converted to agriculture are likely to remain relatively unchanged in the future (Duraiappah *et al.*, 2005).

In industrialized countries most development scenarios propose a decrease in agricultural land, particularly in northern temperate regions (Carpenter *et al.*, 2005; Jenkins, 2003). Regional studies concur with this trend (Ewert *et al.*, 2005; Rounsevell *et al.*, 2005; Verburg *et al.*, 2006). Much agricultural land occurs in areas of high biological value (and this trend is likely to continue in the future Scharlemann *et al.*, 2004). Agricultural land abandonment may, therefore, create opportunities for biodiversity through habitat restoration (Kankaanpää and Carter, 2004; Rounsevell *et al.*, 2006 Rounsevell, 2006, Ro148), notwithstanding interactions with other drivers such as increases in fires due to extreme temperature events. Where the importation of agricultural commodities contributes to land abandonment there may, however, be negative biodiversity impacts on ecosystems from the regions producing these imports (Cyranoski, 2005 De Oliveira, 2005, Ethanol; Commission of the European Communities, 2006). Thus, the distribution and flow of global food commodities is important to understanding cross-biome impacts. An alternative to agricultural land abandonment is extensification (e.g. through organic production) that may also have benefits for biodiversity by better accommodating native species (Rounsevell *et al.*, 2005; Rounsevell *et al.*, 2006). Regional scale analyses that integrate climate and land use change have been dominated by European studies (Dirnbock *et al.*, 2003; Stefanescu *et al.*, 2004; Holman *et al.*, 2005b; Holman *et al.*, 2005a; Scheller and Mladenoff, 2005; Araújo *et al.*, 2006; de Chazal *et al.*, 2007; Giupponi *et al.*, 2006; Harrison *et al.*, 2006; Metzger *et al.*, 2006; Schroter *et al.*, 2005; Rounsevell *et al.*, 2006). Studies on biodiversity in other world regions (e.g. North America and China) have tended to focus on the impacts of land use change in isolation (Lu *et al.*, 2004; Santelmann *et al.*, 2004; Conway and Lathrop, 2005). The effects of land use change on species at the regional scale may further fragment the overall trends arising from climate change (Harrison *et al.*, 2006; Del Barrio *et al.*, 2006; Rounsevell *et al.*, 2006; Holman *et al.*, 2005a). Habitat fragmentation is exacerbated when species have relatively low dispersal distances (Del Barrio *et al.*, 2006) and land use change favours some species over others, depending on the relative 'hostility' of the new environment (Giupponi *et al.*, 2006). For example, agricultural abandonment in mountain regions will increase the distribution of forest species as forests encroach and decrease the distribution of open habitat (grassland) species (Giupponi *et al.*, 2006).

Vagile animals such as polar bears (sea ice biome, tundra; Box 4.4) and in particular migratory birds (tundra, wetlands, lakes, tropical forests etc., Box 4.6) are representatives of the need to analyze impacts both within and across biomes. Many species breed in one area then move to another to spend the non-breeding season (Robinson *et al.*, 2005). Indeed, many migratory species may be more vulnerable to climate change than resident species (Price and Root, 2005). As migratory species often move annually in response to seasonal climate changes, their behaviour, including migratory routes are highly sensitive to climate change. Indeed numerous studies have found that many of these species are arriving earlier (Chapter 1, e.g. Root *et al.*, 2003). Changes in the timing of biological events are of particular concern because of a potential disconnect between migrants and their food resources if the phenology of each advance at different rates (Inouye *et al.*, 2000; Root *et al.*, 2003; Visser *et al.*, 2004). The potential impact of climate change on migratory birds has been especially well studied (Box 4.6).

Box 4.6: Crossing biomes – impacts of climate change on migratory birds

Migratory species can be impacted by climate change in their breeding, wintering and/or critical stopover habitats. Models project changes in the future ranges of many species (Crick, 2004; Peterson *et al.*, 2002; Price and Glick, 2002), some suggesting that the ranges of migrants may shift to a greater extent than non-migrants (Price and Root, 2001). In some cases this may lead to a lengthening and in others to a shortening of migration routes. Moreover, changes in wind patterns, in particular in relation to seasonal migration timing, could help or hinder migration (Butler *et al.*, 1997). Other expected impacts include continuing changes in phenology, behavior, population sizes, and possibly genetics (reviewed in Crick, 2004; Robinson *et al.*, 2005).

Many migratory species must cross barriers, e.g., the Sahara Desert, in moving between their wintering and breeding areas. Many species must stop in the Sahel to refuel en route from their breeding to their wintering areas. Degradation of vegetation quality in the Sahel (Box 4.3) could potentially lead to population declines in these species (Robinson *et al.*, 2005).

More than 80% of the species living within the Arctic Circle winter farther south (Robinson *et al.*, 2005). However, climate induced habitat change may be greatest in the Arctic (Symon *et al.*, 2005; Zockler and Lysenko, 2000). For example, the Red Knot could potentially lose 16%-33% of its tundra breeding habitat by 2100 (HadCM2a1, UKMO). Additionally, at least some populations of this species could lose critical migratory stopover habitat (Delaware Bay, U.S.A.) to sea-level rise (Galbraith *et al.*, 2002).

The breeding areas of many Arctic breeding waterfowl are projected to decline by 10-93% (Zockler and Lysenko, 2000). In North America’s Prairie Pothole region, models have projected an increase in drought with a 3°C regional temperature increase and varying changes in precipitation, leading to large losses of wetlands and to declines in the populations of waterfowl breeding there (Johnson *et al.*, 2005). Many of these species also winter in coastal areas vulnerable to sea-level rise (Inkley *et al.*, 2004).

Declines or range shifts in almost any species will have at least some impact on ecosystem services. For migrants, these impacts are spread over two or more areas. Some of these ecosystem services are intrinsic (pollination, insect control, seed dispersal) and some are extrinsic (existence value, recreation, subsistence, spiritual, religion). These services were discussed in the TAR and a more detailed discussion of services and recreational values can be found elsewhere (Price, 2003; Price and Glick, 2002).

Impacts of climate change will transcend across biomes. Higher CO2 concentrations lower the nutritional quality of the terrestrial litter (Lindroth *et al.*, 2001; Tuchman *et al.*, 2002; Tuchman *et al.*, 2003a; Tuchman *et al.*, 2003b) which in turn will affect the food web relationships of benthic communities in rivers. Greater amount of DOC released in the peatlands at higher CO2 levels is exported to the streams and finally reaches the coastal waters (Freeman *et al.*, 2004).

Increasing global temperatures would shift the geographic ranges of marine biomes to higher latitudes or tidal heights due to changes in sea-level (time of exposure), and air and water temperature, but could also cause localised extinctions at "hot spots" (Helmuth *et al.*, 2002). The ability, however, of calcifying organisms to adapt to decreasing carbonate ions by changing their geographical distribution or physiology is unknown.

4.4.11 Global synthesis including impacts on biodiversity

Since the TAR considerable progress has been made in key fields that allow projection of climate change impacts on species and ecosystems, and the synthesis of these combined results provides a picture, still imperfect, of projected impacts. However, two of these key fields, namely bioclimatic (also called niche-based) modelling and dynamic global vegetation modelling (DGVM) remain quite removed from each other in approach, assumptions, limitations of scale and application. Bioclimatic modelling has been reinvigorated by the availability of significant species distribution data, together with finer scale climate data that have allowed this correlative method to be widely applied. Uncertainties are many, and center on the problem of simulating the fundamental vs. realized niche, that in turn undermine confidence in range computation and future projection, ignorance of inter-species interactions, inadequate treatment of dispersal and migration potential, converting range loss projection to risk of extinction, and limited use for rare range-restricted species. In modelling ecosystem function and plant functional type response, there has been a considerably greater leap in understanding and enhanced confidence in the ecophysiological processes affected by climate change and the mechanisms by which climate change may impact biomes, ecosystem components such as soils, fire behaviour and vegetation structure (ie biomass distribution and leaf area index), bolstered by important experimental results. Limitations of DGVM now relate to assumptions of free dispersal of species comprising the abstract plant functional types that make up ecosystem components. Nonetheless, where ecosystem degradation (loss of functional types) is projected using this method, these carry credibility of incorporating lags in ecosystem components and more defensible assumptions than for bioclimatic modelling. Thus, it is reasonable to expect major changes in the DGVM vegetation structure to equate to change in the structure of communities and abundances of populations, leading to geographical shifts of PFT-dominance with major changes in ecosystem function. These in turn will translate into impacts on ecosystem goods and services.

Lower levels of atmospheric CO_2 rise and climate change may be beneficial in some regions, depending on latitude, on the CO_2 responsiveness of plant functional types, and on the natural adaptive capacity of indigenous biota, mainly through range shifts that are now being observed. But as levels of change increase greater impacts are projected while ecosystem and species response may be lagged, especially in forests and in soils. At such tipping points (Fig. 4.5b) crucial services like carbon sequestration may cease to function as they do now. While these points are difficult to identify without substantial uncertainties, they may lead to irreversible effects such as biodiversity loss or, at the very least, impacts that have a slow recovery time (e.g. soils, corals). Climate changes are further imposed on ecosystems already experiencing substantial pressures of largely detrimental effects. Roughly 60% of evaluated ecosystems are currently unsustainably utilised and show increasing signs of degradation (Reid *et al.*, 2005; Hassan *et al.*, 2005). This alone is likely to cause widespread biodiversity loss (Chapin *et al.*, 2000; Jenkins, 2003; Reid *et al.*, 2005), given that 12% to 52% of major species groups (15,589 species) are threatened with global extinction (Baillie *et al.*, 2006). Threat of extinction varies among groups, with birds and amphibians and continental species, particularly at high latitudes and altitudes, generally at greatest risk (Baillie *et al.*, 2006). Climate change trends will exacerbate these pressures substantially, based on improving knowledge about their impacts on biodiversity as function of changes relative to a the current climate (Table 4.2, Fig. 4.5).

Table 4.2: *Projected impacts of climate change on ecosystems and population systems as reported in the literature for different levels of global mean annual temperature rise, ΔT_{glob}, relative to preindustrial climate (event numbers as used in Fig. 4.5). Projections from the literature were harmonized into a common framework by upscaling (where necessary) from local to global temperature rise using the HadCM3 GCM regional output, upon which many of the studies were based, and by using a common global mean temperature reference point for the year 1990 (after Warren, 2006). Whilst some of the literature relates impacts directly to global mean temperature rises (column ΔT_{reg} left blank), many studies give only local temperature rises, ΔT_{reg}, and hence require upscaling (HadCM2/3 IS92a outputs from Hulme et al., 1999 used). Whenever possible the table reports the GCM used.*

No	ΔT_{glob} above pre- industrial	ΔT_{reg} above 1990	Impacts to unique or widespread ecosystems or population systems	Region affected	Assess-ment / GCM	Source
1	**<1**		Increased coral bleaching causes loss of reefs	Caribbean, Indian Ocean, Great Barrier Reef	M / 4 GCMs	2
2	**<1**		Risk extinctions in Dryandra forest	Australia	E	3
3	**<1**		Range loss begins for Golden Bowerbird	Australia	M	4
4	**<1**		Antarctic marine ecosystems affected by continued reductions in krillreducing Adelie penguin populations	Antarctica	E	42
5	**<1**		Range losses begin for animal species in S Africa	S Africa	M / H2, H3	5
6	**1.5**		Coral reefs regionally functionally extinct	Great Barrier Reef, SE Asia, Carribean	M	2
7	**1.5**	1.4	Coral reefs regionally functionally extinct	Indian Ocean	M	9
8	**1.6**		9 – 31% (mean 18%) all species extinct	Globe	M	1
9	**<1.7**	1	8% loss freshwater fish habitat, 15% loss in Rocky Mountains, 9% loss of salmon	N America	M / GCMs range	13
10	**1.7**		10% Global Ecosystems transformed; loss 47% wooded tundra (taiga), 23% cool conifer forest, 21% scrubland, 15% grassland/steppe, 14% savannah, 13% tundra and 12% temperate deciduous forest. Ecosystems variously lose 2 – 47% extent.	Globe	M / 5 GCMS	6
11	**1.7**		Extinction reptiles (7 – 14%) frogs (8 – 18%) birds (7 – 10%), mammals (10 – 15%) in Queensland as 47% of habitat lost	Australia	M / H2	1, 7
12	**1.7**		Extinction plants in Cerrado (38 – 45%, no disperal only)	Brazil	M / H2	1
13	**1.7**		Extinction mammals (2 – 18%), birds (2 – 8%) and butterflies (1 – 11%)	Mexico	M / H2	1
14	**1.8**	1	Risk functional extinction of Golden Bowerbird: habitat reduced by 50%	Australia	M	5
15	**1.8**		Extensive loss/conversion of habitat in Kakadu wetland due to sea level rise and saltwater intrusion	Australia	M / CS	10
16	**2**		Functional extinction of most coral reefs	Globe	M	2
17	**2**		Total loss Arctic summer ice, high risk of extinction of polar bears, walrus, seals, whole ecosystems stressed	Arctic	M	11
18	**2**		42% existing Arctic tundra remains stable	Arctic	M	14

No	ΔT_{glob} above pre- industrial	ΔT_{reg} above 1990	Impacts to unique or widespread ecosystems or population systems	Region affected	Assess-ment / GCM	Source
19	**2**		Millions of Arctic nesting shorebirds lose 10%-45% of breeding area; high Arctic species most at risk.	Arctic	M	14
20	**2**		Millions of Arctic nesting geese lose up to 50% breeding area	Arctic	M	14
21	**2**		Extinction of plants (3-14%)	Europe	M / H2	1
22	**2**		Severe damage (59% loss) to boreal forest	China	M	15
23	**2**	2	16% freshwater fish habitat loss, 28% loss in Rocky Mtns, 18% loss salmon	N America	M / GCMs range	13
24	**1.8 – 2.4**	1 – 2	Alpine systems in Alps can tolerate local temperature rise of 1-2C, but tolerance likely to be negated by land use change	Europe	E	8
25	**2.1**		Extinction of plants (3 – 16%)	Europe	M	1
26	**2.1**	1.4 – 2.6	Extinction butterflies (13 – 23%)	Australia	M / H2	1
27	**2.2**	2	60% N American wood warblers ranges contract, whilst only 8% expand, 4 to 13 (34%) reach “vulnerable” status	N America	M	43
28	**2.2**		15 – 37% (mean 24%) species extinct	Globe	M	1
29	**2.2**		8 – 12% of 277 medium/large mammals from 28 families in 141 African national parks critically endangered or extinct; further 22 – 25% endangered	Africa	M / H2	23
30	**2 – 2.5**		Fish populations decline, wetland ecosystems dry and disappear	Malawi, African Great Lakes	E	20
31	**2 – 2.5**		New England maples at risk impacting tourism	USA (fall colour)	E	20
32	**2.3**	1.8	Extinctions (100% potential range loss) 10% endemics in hotspot for plant biodiversity; 51 – 65% loss of Fynbos	S Africa	M / H2, CSM	24, 44
33	**2.3**		Extinction mammals (2 – 20%), birds (3 – 8%) and butterflies (3 – 15%)	Mexico	M / H2	1
34	**2.3**		Extinction 48 – 57% Cerrado plants	Brazil	M / H2	1
35	**2.3**	1.8	Extinction of 21 – 40% of Proteaceae (based on range loss and species area assumptions)	South Africa	M / H2	1, 44
36	**2.3**		Succulent Karoo reduced to 20% of area, threatening 2800 plants with extinction; 5 S African parks lose > 40% plant species	S Africa	M / H2	5, 25
37	**2.4**		Transformation of ecosystems e.g. 32% of plants move from 44% European area with potential extinction of endemics	N Europe	M	16
38	**2.4**		63 of 165 rivers studied lose >10% of their fish species	World	M / H3	19
39	**2.4**		Large range loss animals & risk extinctions of 11% species	Mexico	M / H2	26
40	**2.5**		Complete loss alpine zone	Australia	E	20
41	**2 – 3**		Amazon collapse – huge loss of biodiversity	S America, Globe	M	21
42	**2.6**		Extinction of plants (4 – 21%)	Europe	M / H2	1
43	**2.6**		20 – 70% loss (average 44%) bird habitat at 4	USA	M	29

No	ΔT_{glob} above pre- in-dustrial	ΔT_{reg} above 1990	Impacts to unique or widespread ecosystems or population systems	Region affected	Assess-ment / GCM	Source
			major coastal sites			
44	**2.6**		21 – 52% (mean 35%) species extinct	Globe	M	1
45	**2.7**		16% global ecosystems transformed: loss 58% wooded tundra, 31% cool conifer forest, 25% scrubland, 20% grassland/steppe, 21% tundra, 21% temperate deciduous forest, 19% savanna. Ecosystems variously lose between 5 and 66% of their extent	Globe	M / 5 GCMs	6
46	**2.7**		2 – 10% European plants critically endangered or extinct; mean species turnover of 48% (spatial range 17 – 75%); mean species loss of 27% (spatial range 1- 68%)	Europe	M / H3	22
47	**2.9**	2.1 – 3.9	Extinction butterflies (21 – 36%)	Australia	M / H2	1
48	**2.9**		Extinction of plants (4 – 100%) as Amazon dries	Amazon	M / H2	1
49	**2.9**	2.1 – 3.9	>50% range loss for 83% of 24 latitudinally restricted endemic butterflies	Australia	M / 10 GCMs	30
50	**3**		21 – 52% (mean 35%) species extinct	Globe	M	1
51	**3**	3	Extinctions of 200 - 300 species (32 – 63%) of alpine flora	New Zealand	M	33
52	**3**		66 of 165 rivers studied lose >10% of their fish species	Globe	M / H3	19
53	**3**		Increased fire frequency converts forest & macquis to scrub, increased pest outbreaks	Mediterranean	M / H3	34
54	**3**		Risk extinction of 90% Hawaiian honeycreeper birds	Hawaii	M	18
55	**3**		Complete loss boreal forest	China	M	15
56	**3**		Large loss migratory bird habitat	Baltic, USA, Mediterranean	M / H3	35, 36
57	**3.1**	2.1 – 2.5	Cloud forest regions lose hundreds of metres of elevational extent, potential extinctions	C. America, Tropical Africa, Indonesia	M / GE	17
58	**3.1**	3	Loss of 9 – 62% mammal species from mountainous areas of Great Basin	USA	M	32
59	**3.1**	3	24% loss freshwater fish habitat, 40% loss in Rocky Mountains, 27% loss of salmon.	N America	M / GCMs range	13
60	**3.1**	3	50% loss world's most productive duck habitat in prairie pothole region	USA	M / GF, H2	37,38
61	**3.1**	2	66% animals lost from Kruger; 29 endangered species lose >50% range; 4 species locally extinct	S Africa	M / H2	27
62	**2.85 – 3.6**	2 – 3	High risk extinction of Golden Bowerbird: at 2C local temperature rise habitat reduced by 90% and at 3C by 96%	Australia	M	4
63	**3.3**	2.5 – 3.0	Extinction mammals (24 – 59%), birds (28 – 40%), butterflies (13 – 70%), other invertebrates (18 – 80%), reptiles (21 – 45%)	South Africa	M / H2	1
64	**3.3**	3.7	Extinction birds (4 – 38%)	Europe	M / H3	1
65	**3.3**		77% loss low tundra	Canada	M	39
66	**3.4**		22% loss coastal wetlands	Globe	M / H2, H3	35

No	ΔT_{glob} above pre- in-dustrial	ΔT_{reg} above 1990	Impacts to unique or widespread ecosystems or population systems	Region affected	Assess-ment / GCM	Source
67	**3.7**		Few ecosystems can adapt	Globe	M	6
68	**3.7**		50% all nature reserves cannot fulfil conservation objectives	Globe	M / 5 GCMs	6
69	**3.7**		22% Global Ecosystems transformed; loss 68% wooded tundra (taiga), 44% cool conifer forest, 34% scrubland, 28% grassland/steppe, 27% savannah, 38% tundra and 26% temperate deciduous forest. Ecosystems variously lose 7 – 74% extent.	Globe	M / GCMs range	6
70	**3.7**	3	50% eucalypts out of range: extinction risks	Australia	M	12
71	**3.7**	2	Extinctions of endemics such as Hawaiian honeycreepers (bird)	Hawaii	M	18
72	**3.7**		3 – 9 species endemic plants extinct/critically endangered; further 15 – 20 endangered	Namibia	M / H3	39
73	**3.7**		30 – 40% of 277 mammals in 141 African parks critically endangered/extinct; 15 – 20% endangered	Africa	M / H3	23
74	**3.8**		60% loss tundra ecosystem	Globe	M	40
75	**3.8**		44% loss taiga ecosystem	Globe	M	40
76	**4**		73% eucalypts displaced from current range: extinction risks	Australia	M	12
77	**4.1**		Parts of the USA lose 30 – 57% neotropical migratory bird species richness	USA	M	43
78	**4.2**	2.5 – 3.5	Loss of forest wintering habitat of Monarch butterfly	Mexico	M / CCC, GF	28
79	**4.2**		30 endemic frogs/mammals extinct, 35 threatened, 90–100% loss Heritage Rainforest	Australia	M	7
80	**4.3**		4 – 24% European plants critically endangered/extinct; mean species turnover of 63% (spatial range 22 – 90%); mean species loss of 42% (spatial range 2.5 – 86%)	Europe	M / H3	22
81	**3.7 – 4.7**	3 – 4	Risk of extinction of Alpine species	Europe	M	41
82	**5.5**		79% loss of bird habitat at 4 major coastal sites	USA	M	29
83	**5.7**		57 endemic frogs/mammals extinct, 8 endangered	Australia	M	7
84	**~5.7**	5	73% eucalypts out of range	Australia	M	12
85	**7.7**		Total extinction of all endemic species of Queensland rainforest	Australia	M	7

*the study of Leemans and Eickhout 2004 used the following GCMs: HadCM2, GFDL, ECHAM4, CSIROMK2, CGCM1

** relative to 1961-1990 temperatures.

Sources: (1-Thomas *et al.*, 2004a; 2-Hoegh-Guldberg, 1999; 3-Gitay *et al.*, 2001; 4-Hilbert *et al.*, 2004; 5-Rutherford *et al.*, 2000; 6-Leemans and Eickhout, 2004; 7-Williams *et al.*, 2003; 8-Theurillat and Guisan, 2001; 9-Sheppard, 2003; 10-Eliot *et al.*, 1999; 11-Symon *et al.*, 2005; 12-Hughes *et al.*, 1996; 13-Preston, 2007; 14-Zockler and Lysenko, 2000; 15-Ni, 2001; 16-Bakkenes *et al.*, 2002; 17-Still *et al.*, 1999; 18-Benning *et al.*, 2002; 19-Xenopoulos *et al.*, 2005; 20-ECF, 2004; 21-Cox *et al.*, 2004; 22-Thuiller *et al.*, 2005; 23-Thuiller *et al.*, 2007; 24-Midgley *et al.*, 2002; 25-Hannah *et al.*, 2002; 26-Peterson *et al.*, 2002; 27-Erasmus *et al.*, 2002; 28-Villers-Ruiz and Trejo-Vazquez, 1998; 29-Galbraith *et al.*, 2002; 30-Beaumont and Hughes, 2002; 31-Kerr and Packer, 1998; 32-McDonald and Brown, 1992; 33-Halloy and Mark, 2003; 34-Mouillot *et al.*, 2002; 35-Nicholls *et al.*, 1999; 36-Najjar, 2000; 37-Sorenson *et al.*, 1998; 38-Johnson *et al.*, 2005; 39-Thuiller *et al.*, 2006; 40-Neilson *et al.*, 1998; 41-Theurillat *et al.*, 1998; 42-Forcada *et al.*, 2006; 43-Price and Root, 2005; 44-Midgley *et al.*, 2003)

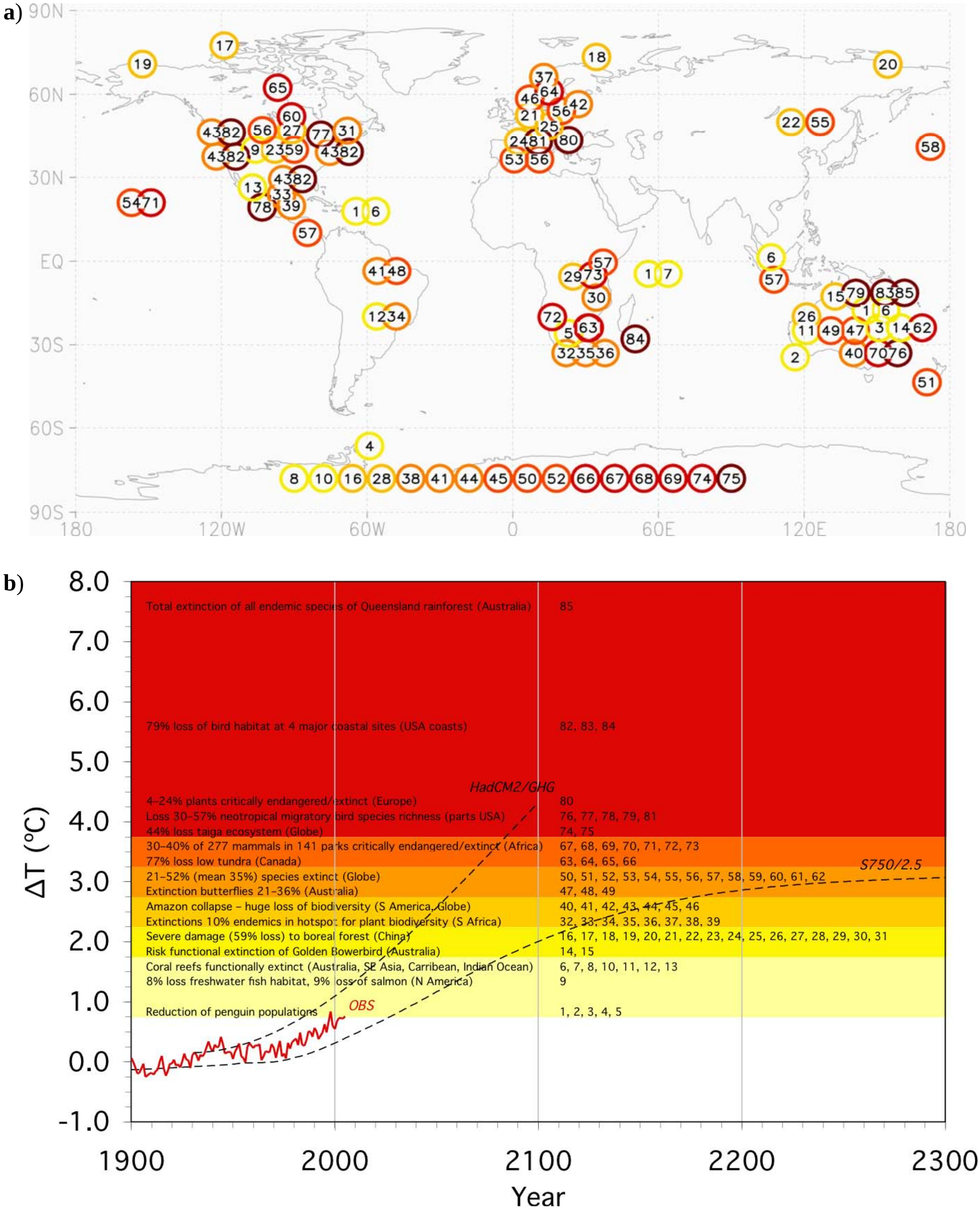

Fig. 4.5: *Critical climate change impacts on ecosystems for different levels of global mean annual temperature rise, ΔT, relative to preindustrial climate: a) where, b) when (approach and event numbers as used in Table 4.2). It is important to note that these impacts do not take account of ancillary stresses on species due to over-harvesting, habitat destruction, landscape fragmentation, alien species invasions, fire regime change, pollution (such as nitrogen deposition), or for plants the potential beneficial effects of rising atmospheric* CO_2.

Unless major changes in policy and way of life take place (Jenkins, 2003), climate change impacts and an intensified human dominance of ecosystems (Vitousek *et al.*, 1997b and others in Science, 277 issue 5325) will diminish the areal extent (e.g. reduction by 5-66% alone due to 2°C warming, Table 4.2, Fig. 4.5) and disrupt nearly all ecosystems of the globe (16% affected alone due to 2°C warming, Table 4.2, Fig. 4.5). Those impacts will vary regionally and across biomes and will lead to a global biodiversity loss, as expressed through area reductions of wild habitats and declines in the abundance of wild species putting those species at risk of extinction (e.g. 3-16% of European plants alone due to 2.1°C or up to 100% of Amazon plants alone due to 2.9°C warming, Table 4.2, Fig. 4.5).

Globally, biodiversity (represented by species richness and relative abundance) may decrease by 12-16% (Sala, 2005) due to a combination of climate and land use changes with tropical forest and woodland, savanna and warm mixed forest accounting for 80% of the species lost (~30,000 species) by 2050. Independent of climate change earlier estimates have projected that about 50% of species being at risk of extinction if 90% of ecosystems would be degraded by land use change pressures or other non-sustainable exploitations (Soulé and Sanjayan, 1998). Overall, through 2050, climate change is estimated to be about twice as strong a driver for biodiversity loss in the Arctic tundra as land use change, whilst in cool conifer forest and savannas it is considered to be 2 to 3 times more important (Carpenter *et al.*, 2005). In other ecosystems land use change may be a stronger driver of biodiversity loss. However, an analysis of the SRES scenarios to 2100 (Strengers *et al.*, 2004) predicts that deforestation ceases in all scenarios except A2, suggesting that beyond 2050 climate change will be the major driver for biodiversity loss rather than land use change. Malcolm *et al*. (2006) find that by 2100 between 1% and 43% of endemic species (average 11.6%) will be committed to extinction, whereas Thomas *et al*. (2004a) report already by 2050 a range from 15% to 37%. Malcolm *et al*. (2006) argue that climate-change induced extinction rates in hotspots for biodiversity in the tropics exceed the predicted extinctions from deforestation, suggesting that at least in some cases climate change is a more serious threat to biodiversity than land use change. In the Mediterranean-climate region of South Africa, climate change may have at least as significant an impact in increasing species extinction risk of endemic Proteas as land use change does by 2020 (Bomhard *et al.*, 2005). In summary, it is likely that only temperate and warm mixed forest species might have a smaller impact from climate change than from land use change. However, if there is a 44% risk of a terrestrial carbon source with a 3°C temperature rise above 1990 (Scholze *et al.*, 2007 see below), this would imply a worldwide decline of forests, at least and suggest here too, that climate change could become a stronger driver of biodiversity loss than land use change.

Loss of biodiversity will lead to decreases in the provision of ecosystem goods and services with trade-offs between ecosystem services likely to intensify (Fig. 1 National Research, 1999; Duraiappah *et al.*, 2005; Carpenter *et al.*, 2005). Gains in provisioning services (e.g., food supply, water use) are projected to occur in part at the expense of other regulating and supporting services including genetic resources, habitat provision, climate and runoff regulation. Projected changes may also increase the likelihood of ecological surprises that are detrimental for human well-being (Duraiappah *et al.*, 2005; Burkett *et al.*, 2005). Ecological surprises include rapid and abrupt changes in temperature and precipitation leading to an increase in extreme events such as floods, fires and landslides, increases in eutrophication, or rapid and sudden increases in disease (Carpenter *et al.*, 2005). This entails also entire ecosystems suddenly shifting their behavior to a new mode (Scheffer *et al.*, 2001; Folke *et al.*, 2004), once gradual pressures such as warming reach a critical level and any services dependent on the previous mode may get lost. Reparation may then become extremely costly or due to hysteresis effects very time consuming, if not impossible.

DGVM modelling of two climate scenarios that represent intermediate low and intermediate high rates (ECHAM5 B2 and HadCM3 A2 respectively) which in ensemble runs generate warming of 2 ºC and 3.8ºC relative to 1980-1999 baseline by 2100 respectively, reveal a potentially complex sequence of ecosystem changes as climate change may evolve (Fig. 4.4, Table 4.3). In the B1 scenario (Fig. 4.4b) undergo 55% of extant ecosystems substantive changes. This scenario reveals some positive impacts especially in Africa and the southern Hemisphere, as desert green-up is projected in southern Africa, the Sahel region, central Australia, and also the Arabian Peninsula and parts of central Asia. As ensemble climate models suggest moderate drying in these regions, therefore this response may be due to a positive impact of rising atmospheric CO_2, previously noted by (Thuiller *et al.*, 2007b) in eastern Namibia, and attributed by them to CO_2 by sensitivity analysis. However, in mid to high latitudes on all continents, substantial shifts in forest structure toward more rain-green, summer-green or deciduous rather than evergreen forest, and forest and woodland decline underlie the overall drop in global terrestrial carbon sequestration potential that occurs post 2030, and approaches a net source by 2100. In the A2 scenario (Fig. 4.4a) undergo 69% of extant ecosystems substantive changes. Desert green-up persists in the regions described above, but substantial decline of forest and woodland at northern, tropical and subtropical latitudes underly a far more negative carbon balance. The current global sink provided by all terrestrial ecosystems deteriorates perhaps already post 2020, and by 2100 and beyond (not shown) the terrestrial biosphere turns globally into an increasing substantial carbon source (Fig. 4 Scholze *et al.*, 2007).

Table 4.3: *Major biome changes projected by LPJ forced by ECHAM5 B1 scenario and HadCM3 A2 scenario (1 – Sabine et al., 2004) (2 – savannas Bonan, 2002; + forest Sabine et al., 2004 - see Fig. 4.2 for explanations and Fig. 4.4 for maps on underlying ecosystem changes)*

Vegetation Change (VC) see Fig. 4.4	Biome area 2000 (Mkm^2)	B1 biome area change ($\Delta T_{2100\text{-preind.}}$ +2°) (Mkm^2)	A2 biome area change ($\Delta T_{2100\text{-preind.}}$ +3.8°C) (Mkm^2)
4: Desert green-up	[1] 27.7	6.2 (+22%)	6.2 (+22%)
6: Forest/woodland decline	[2] 41.6	-4.1 (-12%)	-12.1 (-29%)
1+2+3: Forest/woodland expansion	[2] 41.6	12.7 (+31%)	16.6 (+40%)
1+2+3-6: Net forest/woodland change	-	8.6 (+21%)	4.5 (+11%)

4.5 Costs and valuation of ecosystem goods and services

While many efforts have been made to estimate the economic value of ecosystem goods and servcies (Costanza, 2000; Costanza, 2001; Costanza *et al.*, 1997; Costanza *et al.*, 2000; Daily *et al.*, 2000; Giles, 2005; Reid *et al.*, 2005), others argue that such efforts are not only largely futile and flawed (Pearce, 1998; Toman, 1998b; Bockstael *et al.*, 2000; Pagiola *et al.*, 2004), but may also provide society a disservice (Ludwig, 2000; Kremen, 2005). The estimates range from unknown (incomparibility cf. Chang, 1997) or invaluable, since infinite (Toman, 1998b) because of lack of a human substitute, to ~38×10^{12} USD/a (updated to 2000 levels Costanza *et al.*, 1997; Balmford *et al.*, 2002; Hassan *et al.*, 2005), which is larger but of similar magnitude than the global gross national product (GNP) of 31 $\times 10^{12}$ USD/a (2000 levels). Such monetary estimates are targeted at policy-makers to assist assessments of the economic benefits of our natural environment (Farber *et al.*, 2006). Some argue (Balmford *et al.*, 2002; Reid *et al.*, 2005; Balmford *et al.*, 2005) unless those values are recognized also in economic terms, ecosystems will continue their decline and the planet's ecological health is at stake (Millennium Ecosystem Assessment, 2005c). Others argue that ecosystems provide goods and services which are invaluable and need to be conserved on other, fundamental principles, i.e. the precautionary principle (maximin strategy) for not jeopardizing the conditions for a decent, healthy, and secure human existence on this planet (e.g. Costanza *et al.*, 2000; van den Bergh, 2004). What is sometimes lost in the arguments is that natural capital (including ecosystem goods and services) is part of society's capital assets (Arrow *et al.*, 2004). The question then may be considered as whether one should maximize present value or try to achieve a measure of sustainability. In either case, it is the change in quantities of the capital stock that must be considered (including ecosystem services). One approach in considering valuation of ecosystem services is to calculate how much of one type of capital asset would be needed to compensate for the loss of one unit of another type of capital asset (Arrow *et al.*, 2004). What is not disputed is that factoring in the full value of ecosystem goods and services, whether in monetary or non-monetary terms, distorts measures of economic wealth such that a country may be judged to be growing in wealth according to conventional indicators, while it actually becomes poorer due to the loss of natural resources (Balmford *et al.*, 2002; Millennium Ecosystem Assessment, 2005c; Mock, 2005 p.33ff.). Ignoring such aspects also means loosing out on opportunities to gain. For instance Balmford *et al*. (2002) estimated benefit:cost ratio of at least 100:1 for an effective global conservation program setting aside 15% of current Earth surface if all aspects conventionally ignored are factored in. Finally it is argued that since the poor most directly depend on services from ecosystems, the degradation of these systems will exacerbate poverty, hunger, and disease and obstruct sustainable development (e.g. Mooney *et al.*, 2005; Millennium Ecosystem Assessment, 2005c; Mock, 2005).

4.6 Acclimation and adaptation: practices, options, and constraints

Although climate change is a global issue, local efforts can help greatly in maintaining and enhancing resilience and in limiting the longer-term damage from climate change (e.g. Hughes *et al.*, 2003; Opdam and Wascher, 2004; Singh, 2003). The following section discusses possible adaptation options that could minimize the potential impacts of climate change. Identifying adaptation options is a rapidly developing field, so this list should not be considered exhaustive.

4.6.1 Adaptation options

Adaptation starts with recognition that climate change is occurring and will result in changes in ecosystems (Fig. 4.6). As these changes occur, natural resource management techniques will need to respond in order to increase the resilience of ecosystems or strengthen “ecosystems' ability to respond naturally to climate change” (c.f. Article 2 of the UNFCCC). There are many opportunities to achieve this (Tompkins and Adger, 2003; Cropp and Gabrica, 2002). For effective response, managers must first understand the nature of the climatic and ecological changes that are likely to occur in their region. Monitoring environmental change including climate, and how ecosystems respond is important so that adjustments in management strategies can be made as needed (e.g. Adger *et al.*, 2003; Moldan *et al.*, 2005). Conservation planners and ecosystem managers need, therefore, to be better informed about the potential consequences of climate change. Although, many adaptation options are available to wildlife managers, uncertainty about the magnitude and timing of climate change may discourage some from adopting new management practices. However, management based on ‘no regrets’ or the ‘precautionary principle’ would certainly be prudent. Actions to reduce the impact of other threats could also enhance resilience to climate change (e.g. Opdam and Wascher, 2004). Such pro-active approaches would encourage conservation planning that is both relevant today and in the future. Techniques that allow the management of conservation resources in response to climate variability may ultimately prove to be the most beneficial way of preparing for abrupt climate change by increasing ecosystem resilience (Bharwani *et al.*, 2005).

There are many relatively straightforward options to adapt to the impact of climate change in intensively managed ecosystems (See CH5, agriculture). In less intensively managed ecosystems, decisions have to be made about whether to minimize compositional changes in order to continue the supply of a service or to allow a change in order to supply other ecosystem services. This can be achieved by different management plans, but all require information on the ongoing changes in climate, ecosystems and ecosystem services.

Natural ecosystems or nature reserves (i.e. managed to conserve aspects of biodiversity) are not adaptable. The development of reserve systems, however, can reduce their vulnerability to climate change (McNeely and Schutyser, 2003). Reserve systems should be designed in considering the long-term shifts in plant and animal distributions. Furthermore, reserves should be protected from major disturbances, such as unusual fires and droughts, which increase the likelihood of local extinctions and invasions. Ultimately, adaptation possibilities are determined by the conservation priorities of each reserve. Strategies to cope with climate change should be part of conservation management plans. This is unfortunately rarely the case (Chopra *et al.*, 2005). Adaptation in ecosystems does not occur automatically and it requires adequate resources and financing. This has until now not been widely recognized.

A primary adaptation strategy to climate change is to reduce and manage the other stresses on species and ecosystems (Duraiappah *et al.*, 2005). This may lead to an increase in the resilience of habitats and species to both climate change and climate variability. In addition to removing other stressors it is necessary to maintain healthy, connected and genetically diverse populations. Isolated, small populations are often more prone to local extirpations than larger, more widespread populations (e.g. Gitay *et al.*, 2002; Lovejoy and Hannah, 2005). Connected populations also facilitate the movement of species between them. Although connectivity, genetic diversity and population size are goals managers already strive to accomplish, climate change increases the importance of doing so.

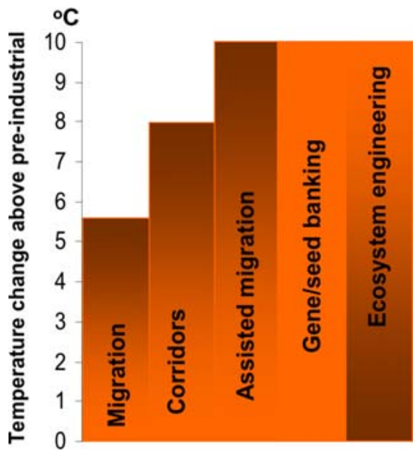

Fig. 4.6: *Phases of adaptive measures of ecosystem management.*

Reducing stress on ecosystems is difficult especially in densely populated regions in Africa, Asia and Europe. Recent studies in southern Africa have signalled the need for policy to focus on managing areas outside protected areas such as subsistence rangelands (Von Maltitz *et al.*, 2007). This can, in part, be achieved through the devolution of resource ownership and management to communities, securing community tenure rights and incentives for resource utilization. This argument is based on the observation that greater species diversity occurs outside protected areas that are more extensive (Scholes *et al.*, 2004). Many species will need to track suitable habitats in response to climate change. Species migration will be difficult to achieve in protected areas without costly interventions such as the establishment of corridors. This contrasts with communal or private land use systems where migration may be encouraged by strategic policies.

Managers can use prescribed fires and other techniques to reduce fuel load and the potential for catastrophic fires. It may also be possible to minimize the effect of severe weather events by for example, securing water rights to maintain water levels through a drought, or by having infrastructure capable of surviving floods. Maintaining viable and widely dispersed populations of individual species also minimizes the probability that localized catastrophic events will cause significant negative effects.

Dispersed populations might also be less vulnerable to wide-spread events such as hurricanes and typhoons.

Climate change is likely to increase opportunities for invasive species because of their adaptability to disturbance (Lake and Leishman, 2004). Captive breeding for reintroduction and translocation is likely to be less successful if climate change is more rapid. Such change could result in large-scale modifications of environmental conditions, including the loss or significant alteration of existing habitat over some or all of a species' range. Captive breeding and translocation should therefore not be perceived as panaceas for the loss of biological diversity that might accompany large changes in the climate. Populations of many species are already perilously small and further loss of habitat and stress associated with severe climate change may push many taxa to extinction.

A costly adaptation option would be the restoration of habitats currently under serious threat or the creation of new habitats in areas where natural colonization is unlikely to occur (Anonymous, 2000). Meshing existing species with new species in a given habitat would, however, be difficult and expensive. In many cases the knowledge of ecosystem interactions and species requirements may be lacking. Engineering habitats to facilitate species movements may require the development of an entirely new field of study.

Ultimately, managers may need to enhance or replace diminished or lost ecosystem services. This could mean manual seed dispersal or reintroducing pollinators for some plant species. In the case of pest outbreaks, the use of pesticides may be necessary. Enhancing or replacing other services, such as contributions to nutrient cycling, ecosystem stability, and ecosystem biodiversity may be much more difficult. The loss or reduced capacity of ecosystem services may be one of the major sources of surprise from climate change and variability.

4.6.2 Adaptation costs

There are no factual studies that have established the effectiveness and costs of adaptation options in ecosystems. Unfortunately, this makes currently a comprehensive assessment of the avoided damages (i.e. benefits) and costs impossible (see also 4.5). But the costs involved in monitoring, increasing the resilience of conservation networks and adaptive management are probably large. For example, the money spent annually on nature conservation in the Netherlands was recently estimated to be 1 billion Euros (Milieu en, 2005). Of this amount, 285 Million Euros were used to manage national parks and reserves and 280 million Euros were used for new reserve network areas and habitat improvement; the main objective being to reduce fragmentation between threatened populations and to respond to other threats. The reserve network planned for the Netherlands (to be established by 2020) will increase the resilience of species, populations and ecosystems to climate change, but at a high cost. Although not defined explicitly in this way, a significant proportion of these costs can be interpreted as climate adaptation costs.

4.6.3 Implications for biodiversity

Many studies and assessments stress the adverse impacts of climate change on biodiversity (e.g. Gitay *et al.*, 2002; Hannah and Lovejoy, 2003; Lovejoy and Hannah, 2005; Thomas *et al.*, 2004a; Thuiller *et al.*, 2005; Schroter *et al.*, 2005; van Vliet and Leemans, 2006), but comprehensive appraisals of adaptation options to deal with declining biodiversity are rare.

The UN Convention on Biological Diversity (CBD, http://www.biodiv.org) aims to conserve biodiversity, to sustainably use biodiversity and its components and to fairly and equitably share benefits arising from the utilization of biodiversity. This goes much further than most national biodiversity policies. The CBD explicitly recognizes the use of biodiversity, ecosystems and their services and frames this as a developmental issue. As such, it extents beyond UNFCCC's objective of 'avoiding dangerous human interference with the climate system at levels where ecosystems cannot adapt naturally, food security is not threatened and economic development can proceed in a sustainable manner'. The main tool proposed by the CBD is the ecosystem approach (EA, Smith and Malthby, 2003) based on integrated response options that intentionally and actively address ecosystem services (including biodiversity) and human well-being simultaneously and involve all stakeholders at different institutional levels. The EA resembles sustainable forest management projects (FAO, 2001). In theory the EA helps the conservation and sustainable use of biodiversity, but applications of the approach have had limited success (Brown *et al.*, 2005a). Integrated responses include, however, learning by doing; a proactive approach that should increase the resilience of ecosystems and biodiversity.

4.6.4 Interactions with other policies and policy implications

An alternative towards designing integrated policies to address climate change and terrestrial systems is to formulate policies that cut across the UN conventions, such as UNFCCC, CBD and Convention to Combat Desertification (CCD, Nnadozie, 1998). Mitigation strategies aimed at combating desertification, for example, would produce a win-win situation. Apart from stopping or reversing desertification, revegetation or re- or afforestation programs contribute towards increased carbon sequestration, increased soil moisture level and ultimately at a regional scale this may positively influence rainfall.

4.7 Implications for sustainable development

All people in the world depend on natural and managed ecosystems and the services they provide. Over the past 50 years, humans have converted and modified these ecosystems more rapidly and over larger areas than in any comparable period of human history. These changes have been driven by the rapidly growing demands for food, fresh water, timber, fibre, and fuel and have contributed to substantial net gains in human well-being and economic development (Reid *et al.*, 2005). However, it has also resulted in a substantial and largely irreversible loss of biodiversity and degradation in ecosystems and their services. The important drivers of ecosystem change are unlikely to disappear with climate change and excessive nutrient loading probably becoming more severe. The continued degradation of ecosystems and biodiversity would jeopardise the livelihoods and well-being of millions of people.

Furthermore, the consequences of policies for the vulnerability of ecosystems to climate change at both the national and international level are not yet fully understood. There is growing evidence that significant impacts on the environment may result from perverse or unintended effects of policies from other sectors, which directly or indirectly have adverse consequences on ecosystems and other environmental processes (Chopra *et al.*, 2005). Land re-distribution policies, for example, designed to increase food self-sufficiency contribute to reducing carbon sequestration, and loss of biodiversity through extensive clear-cutting increases vulnerability to land degradation.

Effective mechanisms to analyze cross-sectoral impacts and to feed new scientific knowledge into policy-making are necessary (Schneider, 2004). For instance, understanding climate variability in arid lands could set a precedent for policies that account for delays in the response of ecosystems to management interventions. Knowing that because of their episodic nature unmanaged arid lands do show immediate negative impacts, policies could be formulated to reduce the temptation of land managers to overstock during "good" periods. The latter is usually very profitable in the short term, but risks degrading the ecosystem in the long term (Ash *et al.*, 2002).

There is a substantial evidence to suggest that developing and implementing policies and strategies to reduce the vulnerability of ecosystems to climate change is closely linked to the availability of capacity to address current needs (e.g. Chanda, 2001). Thus, prospects for successful adaptation to climate change will remain limited as long as factors that contribute to chronic vulnerability to, for example, drought and floods (e.g. population growth, poverty and globalization) are not resolved (Kates, 2000; Reid *et al.*, 2005).

4.7.1 Ecosystems services and sustainable development

There are no simple solutions to the problem of ecosystem degradation and loss of servicesbecause of the large differences in natural and socio-economic conditions between regions. Many interactions, lags and feedbacks, including those that operate across a range of spatial, temporal and organizational scales generate complex patterns, which are not fully understood. Past actions to slow or reverse the degradation of ecosystems have yielded significant results, but these improvements have generally not kept apace with growing pressures (Reid *et al.*, 2005).

Sustainable development means meeting the needs of the present without compromising the ability of future generations to meet their needs. The Millennium Development Goals (MDGs), which include poverty reduction, improved health, education, gender equality, sanitation and environmental sustainability, are a major international policy target towards sustainable development. Any progress achieved in addressing the MDGs is unlikely to be sustained if ecosystem services continue to be degraded. Sound management of ecosystem services provides cost-effective opportunities for addressing multiple development goals in a synergistic manner (Reid *et al.*, 2005).

The role of ecosystems in sustainable development and in achieving the MDGs involves an array of stakeholders, from government, the private sector, international agencies, the local community to individuals (Jain, 2003; chapter 4 Adeel *et al.*, 2005). Evidence from different parts of the world shows that in most cases it is far from clear who is “in charge” of the long term sustainability of an ecosystem, let alone of the situation under future climates. Responding and adapting to the impacts of climate change on ecosystems calls for a clear and structured system of decision making at all levels (Kennett, 2002). Impacts of climate change on ecosystems also show strong interrelationships with ecosystem processes and human activities at various scales over time. Addressing these impacts requires a coordinated, integrated, cross-sectoral policy framework with a long-term focus, a strategy that so far has not been easy to implement (Brown, 2003).

4.7.2 Subsistence livelihoods and indigenous peoples

The impacts of climate change on ecosystems and their services will not be distributed equally around the world. Dryland and Mediterranean regions are likely to be more vulnerable than others (IPCC-TAR) and ecosystem degradation is largest in these regions (Hassan *et al.*, 2005). Climate change is likely to cause additional inequities, as its impacts are unevenly distributed over space and time and disproportionately affect the poor (Tol, 2001). The term double exposure has been used for regions, sectors, ecosystems and social groups that are confronted both by the impacts of climate change and by the consequences of economic globalization (O'Brien and Leichenko, 2000). Thus special attention needs to be given to indigenous peoples with subsistence livelihoods and groups with limited information access and few means of adaptation.

For example, in 1996 the southern African countries developed a policy and strategy for environment and sustainable development. Its goal was "to accelerate economic growth with greater equity and self-reliance; to improve health, income and living conditions of the poor majority: and to ensure equitable and sustainable use of the environment and natural resources for the benefit of present and future generations" (SADC, 1996). However, the implementation of this policy is far from being realized. There is evidence to demonstrate that poverty amongst other factors plays a significant role in degrading ecosystems in developing countries, which also contributes to the failure to meet sustainable development goals (Tole, 1998; Harou, 2002). Unsustainable development and continued degradation affect the poor the most because they depend directly on their immediate ecosystems and have limited resources to invest in conservation or to avoid degradation (Hardy, 2003; Reid *et al.*, 2005). As a result climate change and sustainable development need to incorporate issues of equity (Kates, 2000; Jain, 2003; Richards, 2003).

4.8 Key uncertainties and research priorities

Major sources of uncertainties for this assessment are (i) that projections for precipitation carry a significantly higher uncertainty than temperature, which is also of great relevance for ecosystems in the southern hemisphere; (ii) that within global vegetation models upscaling of ecophysiological processes to the global scale and the role of disturbance regimes are poorly understood, which hampers the assessment of related biotic feedbacks; (iii) that crucial information is drawn from species realized niches only instead of fundamental niches, which is particularly relevant for biodiversity projections; (iv) that the role of invasive alien species in a changing climate for both biodiversity and ecosystem functioning is still poorly understood and may result in major surprises; (v) that abrupt events, such as the slowing of the thermohaline circulation may affect marine ecosystems in unknown ways; (vi) that the only recently considered effect of increasing surface ocean CO_2 and declining pH on marine productivity, biodiversity, biogeochemsitry and ecosystem functioning is poorly understood, yet future research may confirm the initial findings that marine ecosystems will be impacted in significant ways; (vii) that changes in human use and management of ecosystems will interact with climate change in ways that are currently difficult to predict.

To project the future properties and services of ecoystems following research needs arise:

- Identifying tipping points of **permafrost–soil–vegetation interactions** at strongest warming high latitudes, where terrestrial as well as marine (below 100 m) permafrost and gas hydrates store more than 10,000 PgC (CH_4, CO_2), which, if released, could result in abrupt and significant climate forcing (e.g. Symon *et al.*, 2005 1015; iLeaps, 2005; Schellnhuber, 2002).
- More robust modeling of interactions between biota and their geophysical environment using several, independently developed **DGVM**s. To expand such research from the stagnation since TAR better funding, in particular of the costly but needed validation (Price *et al.*, 2001) leading beyond model intercomparisons, is required. The goal is to better project the long-term evolution of the carbon sequestration potential of ecosystems including any lagged responses (e.g. Scheffer *et al.*, 2001; iLeaps, 2005).
- More emphasis on precipitation projections (e.g. Handel and Risbey, 1992) and resulting **water regime** effects to be studied in particular in mature forests in the northern hemisphere, seasonal tropical forests, and arid or semi-arid grassland and savanna systems in the southern hemisphere (e.g. Jasienski *et al.*, 1998; Karnosky, 2003).
- Improved understanding of **disturbances**, in particular episodic events such as drought, fire, insect calamities, diseases, floods, and wind-storms including invasions by alien species, as they interact with ecosystem responses to climate change (e.g. Osmond *et al.*, 2004; Opdam and Wascher, 2004).
- Urgent need to expand current under-investment in **large spatial scale, long-term field studies** (May, 1999b; Krauchi *et al.*, 2000; Morgan *et al.*, 2001b; Osmond *et al.*, 2004; Opdam and

Wascher, 2004; Symon *et al.*, 2005 1019) also to better address scale mismatches between climatology and ecology (Root and Schneider, 1995).

- Urgent promotion of studies on impacts of rising atmospheric CO_2, **ocean acidification**, and warming on coral reef and other marine systems (Coles and Brown, 2003; Anonymous, 2007)
- Advances in understanding the relationship between **biodiversity** and ecosystem services at a scale relevant to human well-being or with Sir Robert May's (1999a) words: "The relatively rudimentary state of ecological science prevents us from making reliable predictions about how much biological diversity we can lose before natural systems collapse and deprive us of services upon which we depend".
- Progress towards identification of ecosystem service providers, ecoystem structures that determine functionality, environmental key factors influencing provision of services, and quantitative information on **economic impacts** (Toman, 1998a; Winnett, 1998; Kremen, 2005; Symon *et al.*, 2005 1018).
- **Integrative vulnerability** studies on adaptive management responses to preserve biodiversity (including conservation and reservation management), ecosystem function and services in relation to pressures from land-use change and climate change (Kappelle *et al.*, 1999; Symon *et al.*, 2005 1018; Stenseth and Hurrell, 2005; Lorenzoni *et al.*, 2005).

References

Aanes, R., B.E. Saether, F.M. Smith, E.J. Cooper, P.A. Wookey, and N.A. Oritsland, 2002: The Arctic Oscillation predicts effects of climate change in two trophic levels in a high-arctic ecosystem. Ecology Letters, 5(3), pp. 445-453.

Aber, J., R.P. Neilson, S. McNulty, J.M. Lenihan, D. Bachelet, and R.J. Drapek, 2001: Forest processes and global environmental change: Predicting the effects of individual and multiple stressors. Bioscience, 51(9), pp. 735-751.

Adeel, Z., U. Safriel, D. Niemeijer, R. White, G. de Kalbermatten, M. Glantz, B. Salem, R. Scholes, M. Niamir-Fuller, S. Ehui, and V. Yapi-Gnaore (eds.), 2005: Ecosystems and human well-being: desertification synthesis. Island Press, Washington, DC, 36pp.

Adger, W.N., S. Huq, K. Brown, D. Conway, and M. Hulme, 2003: Adaptation to climate change in the developing world. Progress in Development Studies, 3(3), pp. 179-195.

Ainsworth, E.A., and S.P. Long, 2005: What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy. New Phytologist, 165(2), pp. 351-371.

Alcamo, J., K. Kok, G. Busch, J. Priess, B. Eickhout, M. Rounsevell, D. Rothman, and H. M, 2007: Searching for the future of land: scenarios from the local to global scale. In: LUCC Synthesis book [Geist, H., and E.F. Lambin (eds.)]. Springer Verlag, Berlin Germany, pp. Chapter 8, in press.

Allen Consulting Group, 2005: Climate change risk and vulnerability: promoting an efficient adaptation response in Australia. Australian Greenhouse Office, in the Department of the Environment and Heritage, Canberra, Australia, 159pp.

Alverson, K., R. Bradley, K. Briffa, J. Cole, M. Hughes, I. Larocque, T. Pedersen, L. Thompson, and S. Tudhope, 2001: A global paleoclimate observing system. Science, 293(5527), pp. 47-48.

Andreae, M.O., D. Rosenfeld, P. Artaxo, A.A. Costa, G.P. Frank, K.M. Longo, and M.A.F. Silva-Dias, 2004: Smoking rain clouds over the Amazon. Science, 303(5662), pp. 1337-1342.

Andreone, F., J.E. Cadle, N. Cox, F. Glaw, R.A. Nussbaum, C.J. Raxworthy, S.N. Stuart, D. Vallan, and M. Vences, 2005: Species review of amphibian extinction risks in Madagascar: Conclusions from the global amphibian assessment. Conservation Biology, 19(6), pp. 1790-1802.

Anisimov, O.A., and F.E. Nelson, 1996: Permafrost distribution in the Northern Hemisphere under scenarios of climatic change. Global and Planetary Change, 14(1-2), pp. 59-72.

Anisimov, O.A., N.I. Shiklomanov, and F.E. Nelson, 2002a: Variability of seasonal thaw depth in permafrost regions: a stochastic modeling approach. Ecological Modelling, 153(3), pp. 217-227.

Anisimov, O.A., A.A. Velichko, P.F. Demchenko, A.V. Eliseev, I.I. Mokhov, and V.P. Nechaev, 2002b: Effect of climate change on permafrost in the past, present, and future. Izvestiya Atmospheric and Oceanic Physiscs, 38, pp. S25-S39.

Anonymous, 2000: Potential U.K. adaptation strategies for climate change. DETR Summary Report, Wetherby, West Yorkshire, 19pp.

Anonymous, 2001: Lothar - Der Orkan 1999. Eidg. Forschungsanstalt WSL and Bundesamt für Umwelt, Wald und Landschaft BUWAL, Birmensdorf, Bern.

Anonymous, 2007: Priorities for research on the ocean in a high-co2 world. Symposium on The Ocean in a High-CO2 World, Scientific Committee on Oceanic Research (SCOR) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO, UNESCO Headquarters, Paris, France, 12pp.

Antic, S., R. Laprise, B. Denis, and R. de Elía, 2006: Testing the downscaling ability of a one-way nested regional climate model in regions of complex topography. Climate Dynamics, 26(2-3), pp. 305-325.

Araújo, M.B., W. Thuiller, and R.G. Pearson, 2006: Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography, In press

Arnell, N.W., 1999: The effect of climate change on hydrological regimes in Europe: a continental perspective. Global Environmental Change, 9(1), pp. 5-23.

Arnell, N.W., M.G.R. Cannell, M. Hulme, R.S. Kovats, J.F.B. Mitchell, R.J. Nicholls, M.L. Parry, M.T.J. Livermore, and A. White, 2002: The consequences of CO2 stabilisation for the impacts of climate change. Climatic Change, 53(4), pp. 413-446.

Arrigo, K.R., and D.N. Thomas, 2004: Large scale importance of sea ice biology in the Southern Ocean. Antarctic Science, 16, pp. 471-486.

Arrow, K., P. Dasgupta, L. Goulder, G. Daily, P. Ehrlich, G. Heal, S. Levin, K.G. Maler, S. Schneider, D. Starrett, and B. Walker, 2004: Are we consuming too much? The Journal of Economic Perspectives, 18, pp. 147-172.

Ash, A.J., D.M.S. Smith, and N. Abel, 2002: Land degradation and secondary production in semi-arid and grazing systems: What is the evidence? In: Global desertification. Do humans cause deserts? [Reynolds, J.F., and D.M. Stafford-Smith (eds.)]. Dahlem University Press, Berlin, Germany, pp. 111-134.

Augustin, L., C. Barbante, P.R.F. Barnes, J.M. Barnola, M. Bigler, E. Castellano, O. Cattani, J. Chappellaz, D. Dahljensen, B. Delmonte, G. Dreyfus, G. Durand, S. Falourd, H. Fischer, J. Fluckiger, M.E. Hansson, P. Huybrechts, R. Jugie, S.J. Johnsen, J. Jouzel, P. Kaufmann, J. Kipfstuhl, F. Lambert, V.Y. Lipenkov, G.V.C. Littot, A. Longinelli, R. Lorrain, V. Maggi, V. Masson-Delmotte, H. Miller, R. Mulvaney, J. Oerlemans, H. Oerter, G. Orombelli, F. Parrenin, D.A. Peel, J.R. Petit, D. Raynaud, C. Ritz, U. Ruth, J. Schwander, U. Siegenthaler, R. Souchez, B. Stauffer, J.P. Steffensen, B. Stenni, T.F. Stocker, I.E. Tabacco, R. Udisti, R.S.W. van de Wal, M. van den Broeke, J. Weiss, F. Wilhelms, J.G. Winther, E.W. Wolff, and M. Zucchelli, 2004: Eight glacial cycles from an Antarctic ice core. Nature (London), 429(6992), pp. 623-628.

Bachelet, D., R.P. Neilson, T. Hickler, R.J. Drapek, J.M. Lenihan, M.T. Sykes, B. Smith, S. Sitch, and K. Thonicke, 2003: Simulating past and future dynamics of natural ecosystems in the United States. Global Biogeochemical Cycles, 17(2), pp. 1045.

Bachelet, D., R.P. Neilson, J.M. Lenihan, and R.J. Drapek, 2001: Climate change effects on vegetation distribution and carbon budget in the United States. Ecosystems, 4(3), pp. 164-185.

Baillie, J.E.M., C. Hilton-Taylor, and S.N. Stuart (eds.), 2006: 2004 IUCN red list of threatened species: a global species assessment. IUCN - The World Conservation Union, Gland, Switzerland and Cambridge, UK., 217pp.

Bakkenes, M., J.R.M. Alkemade, F. Ihle, R. Leemans, and J.B. Latour, 2002: Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050. Global Change Biology, 8(4), pp. 390-407.

Bale, J.S., G.J. Masters, I.D. Hodkinson, C. Awmack, T.M. Bezemer, V.K. Brown, J. Butterfield, A. Buse, J.C. Coulson, J. Farrar, J.E.G. Good, R. Harrington, S. Hartley, T.H. Jones, R.L. Lindroth, M.C. Press, I. Symrnioudis, A.D. Watt, and J.B. Whittaker, 2002: Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology, 8(1), pp. 1-16.

Balmford, A., A. Brunner, P. Cooper, R. Costanza, S. Farber, R.E. Green, M. Jenkins, P. Jefferiss, V. Jessamy, J. Madden, K. Munro, N. Myers, S. Naeem, J. Paavola, M. Rayment, S. Rosendo, J. Roughgarden, K. Trumper, and K. Turner, 2002: Economic reasons for conserving wild nature. Science, 297(9.Aug.), pp. 950-953.

Balmford, A., P. Crane, A. Dobson, R.E. Green, and G.M. Mace, 2005: The 2010 challenge: Data availability, information needs and extraterrestrial insights. Philosophical Transactions of the Royal Society of London - Series B (Biological Sciences), 360(1454), pp. 221-228.

Barbosa, P., G. Libertà, and G. Schmuck, 2003: The European Forest Fires Information System (EFFIS) results on the 2003 fire season in Portugal by the 20th of August.

Barbraud, C., and H. Weimerskirch, 2001: Emperor penguins and climate change. Nature (London), 411(6834), pp. 183-186.

Barnes, D.K.A., D.A. Hodgson, P. Convey, C.S. Allen, and A. Clarke, 2006: Incursion and excursion of Antarctic biota: past, present and future. Global Ecology and Biogeography, 15(2), pp. 121-142.

Bassirirad, H., J.F. Reynolds, R.A. Virginia, and M.H. Brunelle, 1997: Growth and root NO3- and

PO43- uptake capacity of three desert species in response to atmospheric CO2 enrichment. Australian Journal of Plant Physiology, 24(3), pp. 353-358.

Bauder, E.T., 2005: The effects of an unpredictable precipitation regime oin vernal pool hydrology. Freshwater Biology, 50, pp. 2129-2135.

Bazzaz, F.A., 1998: Tropical forests in a future climate: Changes in biological diversity and impact on the global carbon cycle. Climatic Change, 39(2-3), pp. 317-336.

Beaugrand, G., K.M. Brander, J.A. Lindley, S. Souissi, and P.C. Reid, 2003: Plankton effect on cod recruitment in the North Sea. Nature (London), 426(6967), pp. 661-664.

Beaumont, L.J., and L. Hughes, 2002: Potential changes in the distributions of latitudinally restricted Australian butterfly species in response to climate change. Global Change Biology, 8(10), pp. 954-971.

Becker, A., and H. Bugmann, 2001: Global change and mountain regions. IGBP Report, IGBP Secretariat, Royal Swedish Academy of Sciences, Stockholm, 88pp.

Beerling, D.J., and F.I. Woodward, 2001: Vegetation and the terrestrial carbon cycle modelling the first 400 million years. Cambridge University Press, Cambridge, 405pp.

Beever, E.A., P.F. Brussard, and J. Berger, 2003: Patterns of apparent extirpation among isolated populations of pikas (Ochotona princeps) in the Great Basin. Journal of Mammalogy, 84, pp. 37-54.

Behrenfeld, M.J., and P.G. Falkowski, 1997: A consumers guide to phytoplankton primary production models. ,J, a photoadaptive variable (PhO,,), euphotic depth (Z,,), an irradiance-dependent function (F), and daylength (DL). 42(7), pp. 1479-1491.

Bellamy, P.H., P.J. Loveland, R.I. Bradley, R.M. Lark, and G.J.D. Kirk, 2005: Carbon losses from all soils across England and Wales 1978-2003. Nature (London), 437(7056), pp. 245.

Beniston, M., 2000: Environmental change in mountains and uplands. Arnold, London, 172 Spp.

Beniston, M., 2003: Climatic change in mountain regions: A review of possible impacts. Climatic Change, 59(1-2), pp. 5-31.

Beniston, M., 2004: The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations. Geophysical Research Letters, 31(2), pp. art. no.-L02202.

Beniston, M., and P. Jungo, 2002: Shifts in the distributions of pressure, temperature and moisture and changes in the typical weather patterns in the Alpine region in response to the behavior of the North Atlantic Oscillation. Theoretical and Applied Climatology, 71(1-2), pp. 29-42.

Beniston, M., and D.B. Stephenson, 2004: Extreme climatic events and their evolution under changing climatic conditions. Global and Planetary Change, 44(1-4), pp. 1-9.

Benning, T.L., D. Lapointe, C.T. Atkinson, and P.M. Vitousek, 2002: Interactions of climate change with biological invasions and land use in the Hawaiian Islands: Modeling the fate of endemic birds using a geographic information system. Proceedings of the National Academy of sciences of the United States of America, 99(22), pp. 14246-14249.

Berendse, F., N. van Breemen, H. Kanrydin, A. Buttler, M. Heijmans, M.R. Hoosbeek, J. Lee, E. Mitchell, T. Saarinen, H. Vassander, and B. Wallen, 2001: Raised atmospheric CO2 levelsand increased N deposition cause shifts in plant species composition ands production in Sphagnum bogs. Global Change Biology, 7, pp. 591-598.

Bergengren, J.C., S.L. Thompson, D. Pollard, and R.M. Deconto, 2001: Modeling global climate-vegetation interactions in a doubled CO2 world. Climatic Change, 50(1-2), pp. 31-75.

Bergot, M., E. Cloppet, V. Perarnaud, M. Deque, B. Marcais, and M.L. Desprez-Loustau, 2004: Simulation of potential range expansion of oak disease caused by Phytophthora cinnamomi under climate change. Global Change Biology, 10(9), pp. 1539-1552.

Bergstrom, S., B. Carlsson, M. Gardelin, G. Lindstrom, A. Pettersson, and M. Rummukainen, 2001: Climate change impacts on runoff in Sweden - assessments by global climate models, dynamical downscaling and hydrological modelling. Climate Research, 16(2), pp. 101-112.

Bernhoft, A., J.U. Skaare, O. Wiig, A.E. Derocher, and H.J.S. Larsen, 2000: Possible immunotoxic effects of organochlorines in polar bears (Ursus maritimus) at Svalbard.

Journal of Toxicology and Environmental Health - Part A, 59(7), pp. 561-574.
Berry, P.M., M.D.A. Rounsevell, P.A. Harrison, and E. Audsley, 2006: Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation. Environmental Science and Policy, 9, pp. 189-204.
Berthelot, M., P. Friedlingstein, P. Ciais, P. Monfray, J.L. Dufresne, H. Le Treut, and L. Fairhead, 2002: Global response of the terrestrial biosphere to CO2 and climate change using a coupled climate-carbon cycle model. Global Biogeochemical Cycles, 16(4)
Betts, R.A., 2000: Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. Nature (London), 408(9.Nov.), pp. 187-190.
Betts, R.A., P.M. Cox, M. Collins, P.P. Harris, C. Huntingford, and C.D. Jones, 2004: The role of ecosystem-atmosphere interactions in simulated Amazonian precipitation decrease and forest dieback under global climate warming. Theoretical and Applied Climatology, 78(1 - 3), pp. 157-175.
Betts, R.A., P.M. Cox, and F.I. Woodward, 2000: Simulated responses of potential vegetation to doubled-CO2 climate change and feedbacks on near-surface temperature. Global Ecology and Biogeography, 9(2), pp. 171-180.
Bharwani, S., M. Bithell, T.E. Downing, M. New, R. Washington, and G. Ziervogel, 2005: Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 360(1463), pp. 2183-2194.
Billings, S.A., S.M. Schaeffer, and R.D. Evans, 2003: Nitrogen fixation by biological soil crusts and heterotrophic bacteria in an intact Mojave Desert ecosystem with elevated CO2 and added soil carbon. Soil Biology and Biochemistry, 35(5), pp. 643-649.
Blaschke, L., M. Schulte, A. Raschi, N. Slee, H. Rennenberg, and A. Polle, 2001: Photosynthesis, soluble and structural carbon compounds in two Mediterranean oak species (Quercus pubescens and Q-ilex) after lifetime growth at naturally elevated CO2 concentrations. Plant Biology, 3(3), pp. 288-297.
Bockstael, N.E., A.M. Freeman, R.J. Kopp, P.R. Portney, and V.K. Smith, 2000: On measuring economic values for nature. Environmental Science and Technology, 34(8), pp. 1384-1389.
Boere, G.C., and D. Taylor, 2004: Global and regional governmental policy and treaties as tools towards the mitigation of the effect of climate change on waterbirds.
Ibis : The International Journal of Avian Science, 146 (Suppl.1, pp. 111-119.
Boland, G.J., M.S. Melzer, A. Hopkin, V. Higgins, and A. Nassuth, 2004: Climate change and plant diseases in Ontario. Canadian Journal of Plant Pathology, 26(3), pp. 335-350.
Bomhard, B., D.M. Richardson, J.S. Donaldson, G.O. Hughes, G.F. Midgley, D.C. Raimondo, A.G. Rebelo, M. Rouget, and W. Thuiller, 2005: Potential impacts of future land use and climate change on the Red List status of the Proteaceae in the Cape Floristic Region, South Africa. Global Change Biology, 11(9), pp. 1452-1468.
Bonan, G.B., 2002: Ecological climatology: concepts and applications. Cambridge University Press, Cambridge, 678pp.
Bond, W.J., and J.E. Keeley, 2005: Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. Trends in Ecology and Evolution, 20(7), pp. 387-394.
Bond, W.J., and G.F. Midgley, 2000: A proposed CO2-controlled mechanism of woody plant invasion in grasslands and savannas. Global Change Biology, 6(8), pp. 865-869.
Bond, W.J., G.F. Midgley, and F.I. Woodward, 2003: The importance of low atmospheric CO2 and fire in promoting the spread of grasslands and savannas. Global Change Biology, 9(7), pp. 973-982.
Bond, W.J., and J.J. Midgley, 2003: The evolutionary ecology of sprouting in woody plants. International Journal of Plant Sciences, 164(3), pp. S103-S114.
Bond, W.J., F.I. Woodward, and G.F. Midgley, 2005: The global distribution of ecosystems in a world without fire. New Phytologist, 165(2), pp. 525-537.
Bopp, L., O. Aumont, S. Belviso, and P. Monfray, 2003: Potential impact of climate change on marine

dimethyl sulfide emissions. Tellus - Series B: Chemical and physical meteorology, 55(1), pp. 11-22.

Bopp, L., O. Boucher, O. Aumont, S. Belviso, J.L. Dufresne, M. Pham, and P. Monfray, 2004: Will marine dimethylsulfide emissions amplify or alleviate global warming? A model study. Canadian Journal of Fisheries and Aquatic Sciences, 61(5), pp. 826-835.

Borghetti, M., S. Cinnirella, F. Magnani, and A. Saracino, 1998: Impact of long-term drought on xylem embolism and growth in Pinus halepensis Mill. Trees Structure and Function, 12(4), pp. 187-195.

Bortenschlager, S., 1993: Das höchst gelegene Moor der Ostalpen “Moor am Rofenberg” 2760 m. Festschrift Zoller, Diss. Bot. No. 196, 329-334pp.

Bowman, D.M.J.S., A. Walsh, and D.J. Milne, 2001: Forest expansion and grassland contraction within a Eucalyptus savanna matrix between 1941 and 1994 at Litchfield National Park in the Australian monsoon tropics. Global Ecology and Biogeography, 10(5), pp. 535-548.

Braun, S., C. Schindler, R. Volz, and W. Fluckiger, 2003: Forest damages by the storm 'Lothar' in permanent observation plots in Switzerland: The significance of soil acidification and nitrogen deposition. Water, Air, & Soil Pollution, 142(1-4), pp. 327-340.

Brooks, M.L., C.M. D'Antonio, D.M. Richardson, J.B. Grace, J.E. Keeley, J.M. Ditomaso, R.J. Hobbs, M. Pellant, and D. Pyke, 2004: Effects of invasive alien plants on fire regimes. Bioscience, 54(7), pp. 677-688.

Brown, K., 2003: Integrating conservation and development: a case of institutional misfit. Frontiers in Ecology and the Environment, 1(9), pp. 479-487.

Brown, K., J. Mackensen, S. Rosendo, K. Viswanathan, L. Cimarrusti, K. Fernando, C. Morsello, I.M. Siason, S. Singh, I. Susilowati, M. Soccoro Manguiat, G. Bialluch, and W.F. Perrin, 2005a: Integrated responses. In: Ecosystems and human well-being - volume 3: policy responses [Chopra, K., R. Leemans, P. Kumar, and H. Simons (eds.)]. Island Press, Washington DC, pp. 425-464.

Brown, K.J., J.S. Clark, E.C. Grimm, J.J. Donovan, P.G. Mueller, B.C.S. Hansen, and I. Stefanova, 2005b: Fire cycles in North American interior grasslands and their relation to prairie drought. Proceedings of the National Academy of sciences of the United States of America, 102(25), pp. 8865-8870.

Brown, T.J., B.L. Hall, and A.L. Westerling, 2004: The impact of twenty-first century climate change on wildland fire danger in the western United States: An applications perspective. Climatic Change, 62(1-3), pp. 365-388.

Buchmann, N., 2002: Plant ecophysiology and forest response to global change. Tree Physiology, 22(15-16), pp. 1177-1184.

Buddemeier, R.W., J.A. Kleypas, and R.B. Aronson, 2004: Coral reefs & global climate change: potential contributions of climate change to stresses on coral reefs ecosystems. Pew Center on Global Climatic Change, Arlington, USA, Arlington, 44pp.

Bugmann, H., 1997: Sensitivity of forests in the European Alps to future climatic change. Climate Research, 8(1), pp. 35-44.

Bugmann, H., B. Zierl, and S. Schumacher, 2005: Projecting the impacts of climate change on mountain forests and landscapes. In: Global change and mountain regions: an overview of current knowledge [Huber, U.M., H.K.M. Bugmann, and M.A. Reasoner (eds.)]. Springer, Berlin, pp. 477-488.

Burkett, V.R., D.A. Wilcox, R. Stottlemyer, W. Barrow, D. Fagre, J. Baron, J. Price, J.L. Nielsen, C.D. Allen, D.L. Peterson, G. Ruggerone, and T. Doyle, 2005: Nonlinear dynamics in ecosystem response to climatic change: Case studies and policy implications. Ecological Complexity, 2(4), pp. 357-394.

Bush, M.B., M.R. Silman, and D.H. Urrego, 2004: 48,000 years of climate and forest change in a biodiversity hot spot. Science, 303(5659), pp. 827-829.

Butler, R.W., T.D. Williams, N. Warnock, and M. Bishop, 1997: Wind assistance: a requirement for shorebird migration. Auk, 114, pp. 456-466.

Cairns, D.M., and J. Moen, 2004: Herbivory influences tree lines. Journal of Ecology, 92(6), pp. 1019-

1024.
Caldeira, K., and M.E. Wickett, 2003: Anthropogenic carbon and ocean pH. Nature (London), 425(6956), pp. 365-365.
Callaghan, T.V., L.O. Björn, F.S. Chapin Iii, Y. Chernov, T.R. Christensen, B. Huntley, R. Ims, M. Johansson, D.J. Riedlinger, S. Jonasson, N. Matveyeva, W. Oechel, N. Panikov, and G. Shaver, 2005: Arctic tundra and polar desert ecosystems. In: Arctic climate impact assessment (ACIA) - scientific report [Symon, C., L. Arris, and B. Heal (eds.)]. Cambridge Univ. Press, Cambridge, UK, pp. 243-352.
Callaghan, T.V., L.O. Bjorn, Y. Chernov, T. Chapin, T.R. Christensen, B. Huntley, R.A. Ims, M. Johansson, D. Jolly, S. Jonasson, N. Matveyeva, N. Panikov, W. Oechel, and G. Shaver, 2004a: Effects on the function of arctic ecosystems in the short- and long-term perspectives. Ambio, 33(7), pp. 448-458.
Callaghan, T.V., L.O. Bjorn, Y. Chernov, T. Chapin, T.R. Christensen, B. Huntley, R.A. Ims, M. Johansson, D. Jolly, S. Jonasson, N. Matveyeva, N. Panikov, W. Oechel, G. Shaver, and H. Henttonen, 2004b: Effects on the structure of arctic ecosystems in the short- and long-term perspectives. Ambio, 33(7), pp. 436-447.
Callaghan, T.V., L.O. Bjorn, Y. Chernov, T. Chapin, T.R. Christensen, B. Huntley, R.A. Ims, M. Johansson, D. Jolly, S. Jonasson, N. Matveyeva, N. Panikov, W. Oechel, G. Shaver, S. Schaphoff, and S. Sitch, 2004c: Effects of changes in climate on landscape and regional processes, and feedbacks to the climate system. Ambio, 33(7), pp. 459-468.
Camarero, J.J., E. Gutierrez, and M.J. Fortin, 2000: Boundary detection in altitudinal treeline ecotones in the Spanish central pyrenees. Arctic, Antarctic, and Alpine Research, 32(2), pp. 117-126.
Camill, P., 2005: Permafrost thaw accelerates in boreal peatlands during late-20th century climate warming. Climatic Change, 68(1-2), pp. 135-152.
Camill, P., and J.S. Clark, 1998: Climate change disequilibrium of boreal permafrost peatlands caused by local processes. American Naturalist, 151(3), pp. 207-222.
Camill, P., and J.S. Clark, 2000: Long-term perspectives on lagged ecosystem responses to climate change: Permafrost in boreal peatlands and the Grassland/Woodland boundary. Ecosystems, 3(6), pp. 534-544.
Canadell, J.G., P. Ciais, P. Cox, and M. Heimann, 2004: Quantifying, understanding and managing the carbon cycle in the next decades. Climatic Change, 67(2-3), pp. 147-160.
Capistrano, D., Samper K, C, M.J. Lee, and C. Raudsepp-Hearne (eds.), 2005: Ecosystems and human well-being - volume 4: multiscale assessments. Island Press, Washington, DC, 388pp.
Carpenter, S., P. Pingali, E. Bennett, and M. Zurek (eds.), 2005: Ecosystems and human well-being - volume 2: scenarios. Island Press, Washington, DC, 560pp.
Carroll, A.L., S.W. Taylor, J. Régniêre, and L. Safranyik, 2004: Effects of climate change on range expansion by the mountain pine beetle in British Columbia. In: Mountain Pine Beetle Symposium: Challenges and Solutions [Shore, T.L., J.E. Brooks, and J.E. Stone (eds.)]. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information, pp. 223-232.
Cech, P., S. Pepin, and C. Körner, 2003: Elevated CO2 reduces sap flux in mature deciduous forest trees. Oecologia, 137(2), pp. 258-268.
Cesar, H., L. Burke, and L. Pet-Soede, 2003: The economics of worldwide coral reefs degradation. Cesar Environmental Economics Consulting (CEEC), Arnhem, The Netherlands, 23pp.
Chanda, R., 2001: Safe-guarding the globe or basic well-being? Global environmental change issues and Southern Africa. In: Globalization, Democracy and Development in Africa. [T, A, S.M, R, and A. A.G.M (eds.)]. Organisation of Social Science Reserach in Eastern and Southern Africa (OSSREA), Addis Ababa, pp. 246-262.
Chang, R. (ed.), 1997: Incommensurability, incomparability, and practical reason. Harvard University Press, Cambridge, London, 303pp.
Chapin, F.S., P.A. Matson, and H.A. Mooney, 2002: Principles of terrestrial ecosystem ecology. Springer., New York.

Chapin, F.S., Murphy, D. Wall, and C. Zockler, 2005a: Polar systems. In: Ecosystems and human well-being - volume 1: current state & trends [Hassan, R., R. Scholes, and N. Ash (eds.)]. Island Press, Washington, DC, pp. 717-746.
Chapin, F.S., and G.R. Shaver, 1985: Individualistic Growth-Response of Tundra Plant-Species to Environmental Manipulations in the Field. Ecology, 66(2), pp. 564-576.
Chapin, F.S., and A.M. Starfield, 1997: Time lags and novel ecosystems in response to transient climatic change in arctic Alaska. Climatic Change, 35(4), pp. 449-461.
Chapin, F.S., M. Sturm, M.C. Serreze, J.P. McFadden, J.R. Key, A.H. Lloyd, A.D. McGuire, T.S. Rupp, A.H. Lynch, J.P. Schimel, J. Beringer, W.L. Chapman, H.E. Epstein, E.S. Euskirchen, L.D. Hinzman, G. Jia, C.L. Ping, K.D. Tape, C.D.C. Thompson, D.A. Walker, and J.M. Welker, 2005b: Role of land-surface changes in arctic summer warming. Science, 310(5748), pp. 657-660.
Chapin, I.F.S., E.S. Zavaleta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D.U. Hooper, S. Lavorel, O.E. Sala, S.E. Hobbie, M.C. Mack, and S. Diaz, 2000: Consequences of changing biodiversity. Nature (London), 405(6783), pp. 234-242.
Chapuis, J.L., Y. Frenot, and M. Lebouvier, 2004: Recovery of native plant communities after eradication of rabbits from the subantarctic Kerguelen Islands, and influence of climate change. Biological Conservation, 117(2), pp. 167-179.
Chauhan, M., and B. Gopal, 2001: Biodiversity and management of Keoladeo National Park (India): A wetland of international importance. In: Biodiversity in Wetlands: Assessment, Function and Conservation. Volume 2. Backhuys Publishers, Leiden, pp. 217-256.
Cheddadi, R., J. Guiot, and D. Jolly, 2001: The Mediterranean vegetation: what if the atmospheric CO2 increased? Landscape Ecology, 16(7), pp. 667-675.
Chidumayo, E.N., 2001: Climate and phenology of savanna vegetation in southern Africa. Journal of Vegetation Science, 12(3), pp. 347-354.
Chimner, R.A., and J.M. Welker, 2005: Ecosystem respiration responses to experimental manipulations of winter and summer precipitation in a Mixedgrass Prairie, WY, USA. Biogeochemistry, 73(1), pp. 257-270.
Chopra, K., R. Leemans, P. Kumar, and H. Simons (eds.), 2005: Ecosystems and human well-being - volume 3: policy responses. Island Press, Washington, DC, 621pp.
Christensen, J., T. Carter, and F. Giorgi, 2002: PRUDENCE employs new methods to assess European climate change. EOS: transactions / American Geophysical Union, 83, pp. 13.
Christensen, T.R., T.R. Johansson, H.J. Akerman, M. Mastepanov, N. Malmer, T. Friborg, P. Crill, and B.H. Svensson, 2004: Thawing sub-arctic permafrost: Effects on vegetation and methane emissions. Geophysical Research Letters, 31(4), pp. L04501.
Chu, C., N.E. Mandrak, and C.K. Minns, 2005: Potential impacts of climate change on the distributions of several common and rare freshwater fishes in Canada. Diversity and Distribution, 11(4), pp. 299-310.
Chytry, M., P. Pysek, L. Tichy, I. Knollová, and J. Danihelka, 2005: Invasions by alien plants in the Czech Republic: a quantitative assessment across habitats. Preslia, 77(4), pp. 339-354.
Ciais, P., M. Reichstein, N. Viovy, A. Granier, J. Ogee, V. Allard, M. Aubinet, N. Buchmann, C. Bernhofer, A. Carrara, F. Chevallier, N. De Noblet, A.D. Friend, P. Friedlingstein, T. Grunwald, B. Heinesch, P. Keronen, A. Knohl, G. Krinner, D. Loustau, G. Manca, G. Matteucci, F. Miglietta, J.M. Ourcival, D. Papale, K. Pilegaard, S. Rambal, G. Seufert, J.F. Soussana, M.J. Sanz, E.D. Schulze, T. Vesala, and R. Valentini, 2005: Europe-wide reduction in primary productivity caused by the heat and drought in 2003. Nature (London), 437(7058), pp. 529-533.
Clark, R.A., and C.L.J. Frid, 2001: Long-term changes in the North Sea ecosystem. Environmental Review, 9(3), pp. 131-187.
Cochrane, M.A., 2003: Fire science for rainforests. Nature (London), 421(6926), pp. 913-919.
Cochrane, M.A., and W.F. Laurance, 2002: Fire as a large-scale edge effect in Amazonian forests. Journal of Tropical Ecology, 18, pp. 311-325.
Cohen, A.S., 2003: Paleolimnology: the history and evolution of lake systems. Oxford University Press, Oxford, 528pp.

Cole, J., 2003: Global change - Dishing the dirt on coral reefs. Nature (London), 421(6924), pp. 705-706.
Coles, S.L., and B.E. Brown, 2003: Coral bleaching - Capacity for acclimatization and adaptation. Advances in Marine Biology, 46, pp. 183-223.
Collatz, G.J., J.A. Berry, and J.S. Clark, 1998: Effects of climate and atmospheric CO2 partial pressure on the global distribution of C-4 grasses: present, past, and future. Oecologia, 114(4), pp. 441-454.
Commission of the European Communities, 2006: Annex to the Communication from the Commission: biomass action plan impact assessment. Commission Staff Working Document, Commission of the European Communities, Brussels, Belgium, 38pp.
Conway, T.M., and R.G. Lathrop, 2005: Alternative land use regulations and environmental impacts: assessing future land use in an urbanizing watershed. Landscape and Urban Planning, 71(1), pp. 1-15.
Cornelissen, J.H.C., T.V. Callaghan, J.M. Alatalo, A. Michelsen, E. Graglia, A.E. Hartley, D.S. Hik, S.E. Hobbie, M.C. Press, C.H. Robinson, G.H.R. Henry, G.R. Shaver, G.K. Phoenix, D.G. Jones, S. Jonasson, F.S. Chapin, U. Molau, C. Neill, J.A. Lee, J.M. Melillo, B. Sveinbjornsson, and R. Aerts, 2001: Global change and arctic ecosystems: is lichen decline a function of increases in vascular plant biomass? Journal of Ecology, 89(6), pp. 984-994.
Costanza, R., 2000: Social goals and the valuation of ecosystem services. Ecosystemsd, 3(1), pp. 4-10.
Costanza, R., 2001: Visions, values, valuation, and the need for an ecological economics. Bioscience, 51(6), pp. 459-468.
Costanza, R., R. D'arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'neill, J. Paruelo, R.G. Raskin, P. Sutton, and M. van den Belt, 1997: The value of the world's ecosystem services and natural capital. Nature (London), 387(15 May), pp. 253-260.
Costanza, R., M. Daly, C. Folke, P. Hawken, C.S. Holling, A.J. McMichael, D. Pimentel, and D. Rapport, 2000: Managing our environmental portfolio. Bioscience, 50(2), pp. 149-155.
Cowling, R.M., F. Ojeda, B. Lamont, P.W. Rundel, and R. Lechmere-Oertel, 2005: Rainfall reliability, a neglected factor in explaining convergence and divergence of plant traits in fire-prone mediterranean-climate ecosystems. Global Ecology and Biogeography, 14(6), pp. 509-519.
Cowling, R.M., P.W. Rundel, B.B. Lamont, M.K. Arroyo, and M. Arianoutsou, 1996: Plant diversity in Mediterranean-climate regions. Trends in Ecology & Evolution, 11(9), pp. 362-366.
Cox, P.M., R.A. Betts, M. Collins, P.P. Harris, C. Huntingford, and C.D. Jones, 2004: Amazonian forest dieback under climate-carbon cycle projections for the 21st century. Theoretical and Applied Climatology, 78(1-3), pp. 137-156.
Cox, P.M., R.A. Betts, C.D. Jones, S.A. Spall, and I.J. Totterdell, 2000: Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature (London), 408(9.Nov.), pp. 184-187.
Craig, P., P. Trail, and T.E. Morrell, 1994: The decline of fruit bats in American-Samoa due to hurricanes and overhunting. Biological Conservation, 69(3), pp. 261-266.
Cramer, W., A. Bondeau, S. Schaphoff, W. Lucht, B. Smith, and S. Sitch, 2004: Tropical forests and the global carbon cycle: impacts of atmospheric carbon dioxide, climate change and rate of deforestation. Philosophical Transactions of the Royal Society of London - Series B (Biological Sciences), 359(1443), pp. 331-343.
Cramer, W., A. Bondeau, F.I. Woodward, I.C. Prentice, R.A. Betts, V. Brovkin, P.M. Cox, V. Fisher, J.A. Foley, A.D. Friend, C. Kucharik, M.R. Lomas, N. Ramankutty, S. Sitch, B. Smith, A. White, and C. Young-Molling, 2001: Global response of terrestrial ecosystem structure and function to CO2 and climate change: results from six dynamic global vegetation models. Global Change Biology, 7(4), pp. 357-373.
Crawford, R.M.M., C.E. Jeffree, and W.G. Rees, 2003: Paludification and forest retreat in northern oceanic environments. Annals of Botany, 91, pp. 213-226.
Crawley, M.J., 1989: Chance and timing in biological invasions. In: Biological invasions: a global perspective [Drake, J., F. Dicastri, R. Groves, F. Kruger, H. Mooney, M. Rejmanek, and M. Williamson (eds.)]. John Wiley, Chichester, pp. 407-423.

Crawley, M.J., P.H. Harvey, and A. Purvis, 1996: Comparative ecology of the native and alien floras of the British Isles. Philosophical Transactions of the Royal Society of London - Series B (Biological Sciences), 351(1345), pp. 1251-1259.
Crick, H.Q.P., 2004: The impact of climate change on birds. Ibis : The International Journal of Avian Science, 146(s1), pp. 48-56.
Cropp, R., and A. Gabrica, 2002: Ecosystem adaptation: do ecosystems maximize resilience? Ecology, 83(7), pp. 2019-2026.
Croxall, J.P., P.N. Trathan, and E.J. Murphy, 2002: Environmental change and Antarctic seabird populations. Science, 297(5586), pp. 1510-1514.
Cubasch, U., G.A. Meehl, G.J. Boer, R.J. Stouffer, M. Dix, A. Noda, C.A. Senior, S. Raper, and K.S. Yap, 2001: Projections of future climate change. In: Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge and New York, pp. 525-582.
Currie, D.J., 2001: Projected effects of climate change on patterns of vertebrate and tree species richness in the conterminous United States. Ecosystems, 4(3), pp. 216-225.
Cyranoski, D., 2005: Malaysia plans 'red book' in its attempts to go green. Nature (London), 436(7049), pp. 313-313.
Daily, G.C., T. Söderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P.R. Ehrlich, C. Folke, A. Jansson, B. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K. Mäler, D. Simpson, D. Starrett, D. Tilman, and B. Walker, 2000: The value of nature and the nature of value. In: Science pp. 395-396.
Daimaru, H., and H. Taoda, 2004: Effects of snow pressure on the distribution of subalpine Abies mariesii forests in northern Honshu Island, Japan. Journal of Agricultural Meteorology, 60(4), pp. 253-261.
Dale, V.H., L.A. Joyce, S. McNulty, and R.P. Neilson, 2000: The interplay between climate change, forests, and disturbances. Science of the Total Environment, 262(3), pp. 201-204.
Daly, C., D. Bachelet, J.M. Lenihan, R.P. Neilson, W. Parton, and D. Ojima, 2000: Dynamic simulation of tree-grass interactions for global change studies. Ecological Applications, 10(2), pp. 449.
Davis, M.B., 1981: Quaternary history and the stability of forest communities. In: Forest succession: concepts and application [West, D.C., H.H. Shugart, and D.B. Botkin (eds.)]. Springer, New York a.o., pp. 132-153.
Davis, M.B., and R.G. Shaw, 2001: Range shifts and adaptive responses to Quaternary climate change. Science, 292(5517), pp. 673-679.
De Angelis, P., K.S. Chigwerewe, and G.E.S. Mugnozza, 2000: Litter quality and decomposition in a CO2-enriched Mediterranean forest ecosystem. Plant & Soil, 224(1), pp. 31-41.
De Bono, A., P. Peduzzi, G. Giuliani, and S. Kluser, 2004: Impacts of summer 2003 heat wave in Europe. Early Warning on Emerging Environmental Threats 2, UNEP: United Nations Environment Programme, Nairobi, Kenya, 4pp.
de Chazal, J., F. Quetier, S. Lavorel, and A. Van Doorn, 2007: Vulnerability assessment in extensive agro-pastoral landscapes of Europe. Ecosystems, pp. (submitted).
de Groot, W.J., P.M. Bothwell, D.H. Carlsson, and K.A. Logan, 2003: Simulating the effects of future fire regimes on western Canadian boreal forests. Journal of Vegetation Science, 14(3), pp. 355-364.
de Koning, F., R. Olschewski, E. Veldkamp, P. Benitez, M. Lopez-Ulloa, T. Schlichter, and M. de Urquiza, 2005: The ecological and economic potential of carbon sequestration in forests: Examples from South America. Ambio, 34(3), pp. 224-229.
de Menocal, P.B., 2004: African climate change and faunal evolution during the Pliocene-Pleistocene. Earth Planetary Science Letters, 220, pp. 3-24.
de Wit, M., and J. Stankiewicz, 2006: Changes in surface water supply across Africa with predicted climate change. Science Express(2 Mar), pp. 1119929.

DeFries, R.S., C.B. Field, I. Fung, G.J. Collatz, and L. Bounoua, 1999: Combining satellite data and biogeochemical models to estimate global effects of human-induced land cover change on carbon emissions and primary productivity. Global Biogeochemical Cycles, 13(3), pp. 803-815.
Del Barrio, G., P.A. Harrison, P.M. Berry, N. Butt, M. Sanjuan, R.G. Pearson, and T.P. Dawson, 2006: Integrating multiple modelling approaches to predict the potential impacts of climate change on species' distributions in contrasting regions: comparison and implications for policy. Environmental Science and Policy, 9, pp. 129-147.
Derocher, A.E., N.J. Lunn, and I. Stirling, 2004: Polar bears in a warming climate. Integrative and Comparative Biology, 44(2), pp. 163-176.
Derocher, A.E., H. Wolkers, T. Colborn, M. Schlabach, T.S. Larsen, and O. Wiig, 2003: Contaminants in Svalbard polar bear samples archived since 1967 and possible population level effects. Science of the Total Environment, 301(1-3), pp. 163-174.
Deutschewitz, K., A. Lausch, I. Kuhn, and S. Klotz, 2003: Native and alien plant species richness in relation to spatial heterogeneity on a regional scale in Germany. Global Ecology and Biogeography, 12(4), pp. 299-311.
Diaz, H.F. (ed.), 2003: Climate variability and change in high elevation regions: past, present & future. Kluwer Academic Publishers, Dordrecht, 282pp.
Diaz, H.F., and V. Markgraf (eds.), 1992: El Niño historical and paleoclimatic aspects of the southern oscillation. Cambridge University Press, Cambridge a.o., 476pp.
Dirnbock, T., S. Dullinger, and G. Grabherr, 2003: A regional impact assessment of climate and land-use change on alpine vegetation. Journal of Biogeography, 30(3), pp. 401-417.
Dixon, R.K., J.B. Smith, S. Brown, O. Masera, L.J. Mata, and I. Buksha, 1999: Simulations of forest system response and feedbacks to global change: experiences and results from the US Country Studies Program. Ecological Modelling, 122(3), pp. 289-305.
Dormann, C.F., and S.J. Woodin, 2002: Climate change in the Arctic: using plant functional types in a meta-analysis of field experiments. Functional Ecology, 16(1), pp. 4-17.
Drake, B.G., M.A. Gonzalezmeler, and S.P. Long, 1997: More efficient plants: A consequence of rising atmospheric CO2? Annual Review of Plant Physiology and Plant Molecular Biology, 48, pp. 609-639.
Dube, O.P., and G. Pickup, 2001: Effects of rainfall variability and communal and semi-commercial grazing on land cover in southern African rangelands. Climate Research, 17(2), pp. 195-208.
Dufresne, J.L., P. Friedlingstein, M. Berthelot, L. Bopp, P. Ciais, L. Fairhead, H. Le Treut, and P. Monfray, 2002: On the magnitude of positive feedback between future climate change and the carbon cycle. Geophysical Research Letters, 29(10)
Dukes, J.S., N.R. Chiariello, E.E. Cleland, L.A. Moore, M.R. Shaw, S. Thayer, T. Tobeck, H.A. Mooney, and C.B. Field, 2005: Responses of grassland production to single and multiple global environmental changes. PLoS Biology, 3(10), pp. 1829-1837.
Dukes, J.S., and H.A. Mooney, 1999: Does global change increase the success of biological invaders? Trends in Ecology and Evolution, 14(4), pp. 135-139.
Dullinger, S., T. Dirnbock, and G. Grabherr, 2004: Modelling climate change-driven treeline shifts: relative effects of temperature increase, dispersal and invasibility. Journal of Ecology, 92(2), pp. 241-252.
Dullinger, S., T. Dirnbock, R. Kock, E. Hochbichler, T. Englisch, N. Sauberer, and G. Grabherr, 2005: Interactions among tree-line conifers: differential effects of pine on spruce and larch. Journal of Ecology, 93(5), pp. 948-957.
Duraiappah, A., S. Naeem, T. Agardi, N. Ash, D. Cooper, S. Díaz, D.P. Faith, G. Mace, J.A. McNeilly, H.A. Mooney, A.A. Oteng-Yeboah, H.M. Pereira, S. Polasky, C. Prip, W.V. Reid, C. Samper, P.J. Schei, R. Scholes, F. Schutyser, and A. van Jaarsveld (eds.), 2005: Ecosystems and human well-being: biodiversity synthesis. Island Press, Washington, DC, 100pp.
Eastman, J.L., M.B. Coughenour, and R.A. Pielke, 2001: The regional effects of CO2 and landscape change using a coupled plant and meteorological model. Global Change Biology, 7(7), pp. 797-815.

ECF (ed.) 2004: What is dangerous climate change? Initial results of a symposium on key vulnerable regions climate change and article 2 of the UNFCCC. International Symposium, Beijing, Inda;27-30 October, ECF: European Climate Forum, Buenos Aires, Argentina, pp. 39.
Edwards, E.J., D.G. Benham, L.A. Marland, and A.H. Fitter, 2004: Root production is determined by radiation flux in a temperate grassland community. Global Change Biology, 10(2), pp. 209-227.
Eliasson, P.E., R.E. McMurtrie, D.A. Pepper, M. Stromgren, S. Linder, and G.I. Agren, 2005: The response of heterotrophic CO2 flux to soil warming. Global Change Biology, 11(1), pp. 167-181.
Eliot, I., C.M. Finlayson, and P. Waterman, 1999: Predicted climate change, sea-level rise and wetland management in the Australian wet-dry tropics. Wetlands Ecology and Management, 7(1 - 2), pp. 63-81.
Enquist, C.A.F., 2002: Predicted regional impacts of climate change on the geographical distribution and diversity of tropical forests in Costa Rica. Journal of Biogeography, 29(4), pp. 519-534.
Epstein, H.E., R.A. Gill, J.M. Paruelo, W.K. Lauenroth, G.J. Jia, and I.C. Burke, 2002: The relative abundance of three plant functional types in temperate grasslands and shrublands of North and South America: effects of projected climate change. Journal of Biogeography, 29(7), pp. 875-888.
Erasmus, B.F.N., A.S. Van Jaarsveld, S.L. Chown, M. Kshatriya, and K.J. Wessels, 2002: Vulnerability of South African animal taxa to climate change. Global Change Biology, 8(7), pp. 679-693.
Evans, R.D., and J. Belnap, 1999: Long-term consequences of disturbance on nitrogen dynamics in an arid ecosystem. Ecology, 80(1), pp. 150-160.
Ewert, F., M.D.A. Rounsevell, I. Reginster, M.J. Metzger, and R. Leemans, 2005: Future scenarios of European agricultural land use I. Estimating changes in crop productivity. Agriculture, Ecosystems and Environment, 107(2-3), pp. 101-116.
Facon, B., B.J. Genton, J. Shykoff, P. Jarne, A. Estoup, and P. David, 2006: A general eco-evolutionary framework for understanding bioinvasions. Trends in Ecology and Evolution, 21(3), pp. 130-135.
FAO, 2001: Global forest resource assessment 2000 - main report. FAO Forestry paper 140, Food and Agriculture Organization of the United Nations, Rome, 479pp.
Farber, S., R. Costanza, D.L. Childers, J. Erickson, K. Gross, M. Grove, C.S. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren, and M. Wilson, 2006: Linking ecology and economics for ecosystem management. Bioscience, 56(2), pp. 121-133.
Fay, P.A., J.D. Carlisle, B.T. Danner, M.S. Lett, J.K. McCarron, C. Stewart, A.K. Knapp, J.M. Blair, and S.L. Collins, 2002: Altered rainfall patterns, gas exchange, and growth in grasses and forbs. International Journal of Plant Sciences, 163, pp. 549-557.
Fay, P.A., J.D. Carlisle, A.K. Knapp, J.M. Blair, and S.L. Collins, 2000: Altering rainfall timing and quantity in a mesic grassland ecosystem: Design and performance of rainfall manipulation shelters. Ecosystems, 3(3), pp. 308-319.
Fay, P.A., J.D. Carlisle, A.K. Knapp, J.M. Blair, and S.L. Collins, 2003: Productivity responses to altered rainfall patterns in a C-4-dominated grassland. Oecologia, 137(2), pp. 245-251.
Feddema, J.J., K.W. Oleson, G.B. Bonan, L.O. Mearns, L.E. Buja, G.A. Meehl, and W.M. Washington, 2005: The importance of land-cover change in simulating future climates. Science, 310(5754), pp. 1674-1678.
Feely, R.A., C.L. Sabine, K. Lee, W. Berelson, J. Kleypas, V.J. Fabry, and F.J. Millero, 2004: Impact of anthropogenic CO2 on the CaCO3 system in the oceans. Science, 305(5682), pp. 362-366.
Ferretti, D., E. Pendall, P.P. Tans, A.R. Mosier, J. Morgan, J.W. White, and J.A. Nelson, 2001: Evaporative Water Loss from Soil Reduced by Elevated Atmospheric CO2. In: abstract, American Geophysical Union, Fall Meeting 2001 San Francisco; 10-14 December.
Field, C.B., M.J. Behrenfeld, J.T. Randerson, and P. Falkowski, 1998: Primary production of the biosphere: integrating terrestrial and oceanic components. Science, 281(10 July), pp. 237-240.
Finlayson, C.M., R. D'cruz, N. Davidson, J. Alder, S. Cork, R. de Groot, C. Lévêque, G.R. Milton, G. Peterson, D. Pritchard, B.D. Ratner, W.V. Reid, C. Revenga, M. Rivera, F. Schutyser, M. Siebentritt, M. Stuip, R. Tharme, S. Butchart, E. Dieme-Amting, H. Gitay, S. Raaymakers, and D.

Taylor (eds.), 2005: Ecosystems and human well-being: wetlands and water synthesis. Island Press, Washington, DC, 80pp.
Fischer, R. (ed.), 2005: Title., United Nations Economic Commission for Europe (UN-ECE), Geneva, Switzerland, 36pp.
Fischlin, A., and D. Gyalistras, 1997: Assessing impacts of climatic change on forests in the Alps. Global Ecology and Biogeography Letters, 6, pp. 19-37.
Fischlin, A., D. Gyalistras, S. Fukutome, and C. Theato, 2007: Impacts of the summer 2003 heat wave on forests as assessed by simulation models. Geophysical Research Letters, pp. in prep.
Flanagan, L.B., L.A. Wever, and P.J. Carlson, 2002: Seasonal and interannual variation in carbon dioxide exchange and carbon balance in a northern temperate grassland. Global Change Biology, 8(7), pp. 599-615.
Flannigan, M.D., B.J. Stocks, and B.M. Wotton, 2000: Climate change and forest fires. Science of the Total Environment, 262(3), pp. 221-229.
Flöder, S., and C.W. Burns, 2004: Phytoplankton diversity of shallow tidal lakes: influence of periodic salinity changes on diversity and species number of a natural assemblage. Journal of Phycology, 40(1), pp. 54-61.
Florenzano, G.T., 2004: Birds as indicators of recent environmental changes in the Apennines (Foreste Casentinesi National Park, central Italy). Italian Journal of Zoology, 71(4), pp. 317-324.
Foden, W., G.F. Midgley, G. Hughes, W.J. Bond, W. Thuiller, M.T. Hoffman, P. Kaleme, A. Rebelo, and L. Hannah, 2007: Namib desert trees feel the heat of climate change. Diversity and Distribution, pp. 21(in press).
Foley, J.A., M.T. Coe, M. Scheffer, and G.L. Wang, 2003: Regime shifts in the Sahara and Sahel: Interactions between ecological and climatic systems in northern Africa. Ecosystems, 6(6), pp. 524-539.
Foley, J.A., R. Defries, G.P. Asner, C. Barford, G. Bonan, S.R. Carpenter, F.S. Chapin, M.T. Coe, G.C. Daily, H.K. Gibbs, J.H. Helkowski, T. Holloway, E.A. Howard, C.J. Kucharik, C. Monfreda, J.A. Patz, I.C. Prentice, N. Ramankutty, and P.K. Snyder, 2005: Global consequences of land use. Science, 309(5734), pp. 570-574.
Foley, J.A., S. Levis, C.I. Prentice, D. Pollard, and S.L. Thompson, 1998: Coupling dynamic models of climate and vegetation. Global Change Biology, 4, pp. 561-679.
Foley, J.A., and N. Ramankutty, 2004: A primer on the terrestrial carbon cycle: What we don't know but should. In: The global carbon cycle - Integrating humans, climate and the natural world [Field, C.B., and M.R. Raupach (eds.)]. Island Press, Washington, D.C., p. 528.
Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C.S. Holling, 2004: Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology Evolution and Systematics, 35, pp. 557-581.
Forbes, B.C., 1995: Effects of surface disturbance on the movement of native and exotic plants under a changing climate. Ecosystems Research Report 10, European Commission, 209-219pp.
Forcada, J., P.N. Trathan, K. Reid, E.J. Murphy, and J.P. Croxall, 2006: Contrasting population changes in sympatric penguin species in association with climate warming. Global Change Biology, 12, pp. 411-423.
Fosberg, M.A., W. Cramer, V. Brovkin, R. Fleming, R. Gardner, A.M. Gill, J.G. Goldammer, R. Keane, P. Koehler, J. Lenihan, R. Neilson, S. Sitch, K. Thornicke, S. Venevski, M.G. Weber, and U. Wittenberg, 1999: Strategy for a fire module in dynamic global vegetation models. International Journal Of Wildland Fire, 9(1), pp. 79.
Foster, P., 2001: The potential negative impacts of global climate change on tropical montane cloud forests. Earth Science Reviews, 55(1-2), pp. 73-106.
Freeman, C., N. Fenner, N.J. Ostle, H. Kang, D.J. Dowrick, B. Reynolds, M.A. Lock, D. Sleep, S. Hughes, and J. Hudson, 2004: Export of dissolved organic carbon from peatlands under elevated carbon dioxide levels. Nature (London), 430(6996), pp. 195-198.
Frei, C., C. Schar, D. Luthi, and H.C. Davies, 1998: Heavy precipitation processes in a warmer climate. Geophysical Research Letters, 25(9), pp. 1431-1434.

Freiwald, A., J.H. Fossa, A. Grehan, T. Koslow, and J.M. Roberts, 2004: Cold-water coral reefs: out of sight no longer out of mind. UNEP-WCMC No. 22, UNEP World Conservation Monitoring Centre, Cambridge, UK.
Frey, K.E., and L.C. Smith, 2005: Amplified carbon release from vast West Siberian peatlands by 2100. Geophysical Research Letters, 32, pp. L09401.
Fried, J.S., M.S. Torn, and E. Mills, 2004: The impact of climate change on wildfire severity: A regional forecast for northern California. Climatic Change, 64(1-2), pp. 169-191.
Fuhlendorf, S.D., D.D. Briske, and F.E. Smeins, 2001: Herbaceous vegetation change in variable rangeland environments: The relative contribution of grazing and climatic variability. Applied Vegetation Science, 4(2), pp. 177-188.
Fuhrer, J., M. Beniston, A. Fischlin, C. Frei, S. Goyette, K. Jasper, and C. Pfister, 2007: Climate risks and their impact on agriculture and forests in Switzerland. Climatic Change, 72, pp. 45 (revised).
Galbraith, H., R. Jones, R. Park, J. Clough, S. Herrod-Julius, B. Harrington, and G. Page, 2002: Global climate change and sea level rise: Potential losses of intertidal habitat for shorebirds. Waterbirds, 25(2), pp. 173-183.
Gan, J.B., 2004: Risk and damage of southern pine beetle outbreaks under global climate change. Forest Ecology and Management, 191(1-3), pp. 61-71.
Gardner, T.A., I.M. Cote, J.A. Gill, A. Grant, and A.R. Watkinson, 2003: Long-term region-wide declines in Caribbean corals. Science, 301(5635), pp. 958-960.
Gaston, K.J., T.M. Blackburn, and K.K. Goldewijk, 2003: Habitat conversion and global avian biodiversity loss. Proceedings of the Royal Society of London - Series B Biological Sciences, 270(1521), pp. 1293-1300.
Gedney, N., P.M. Cox, R.A. Betts, O. Boucher, C. Huntingford, and P.A. Stott, 2006: Detection of a direct carbon dioxide effect in continental river runoff records. Nature (London), 439(7078), pp. 835-838.
Geist, H.J., and E.F. Lambin, 2004: Dynamic causal patterns of desertification. Bioscience, 54(9), pp. 817-829.
Gerber, S., F. Joos, and I.C. Prentice, 2004: Sensitivity of a dynamic global vegetation model to climate and atmospheric CO2. Global Change Biology, 10(8), pp. 1223-1239.
Gerten, D., and R. Adrian, 2002: Species-specific changes in the phenology and peak abundance of freshwater copepods in response to warm summers. Freshwater Biology, 47(11), pp. 2163-2173.
Gerten, D., W. Lucht, S. Schaphoff, W. Cramer, T. Hickler, and W. Wagner, 2005: Hydrologic resilience of the terrestrial biosphere. Geophysical Research Letters, 32(21)
Gerten, D., S. Schaphoff, U. Haberlandt, W. Lucht, and S. Sitch, 2004: Terrestrial vegetation and water balance - hydrological evaluation of a dynamic global vegetation model. Journal of Hydrology, 286(1-4), pp. 249-270.
Gielen, B., H.J. De Boeck, C.M.H.M. Lemmens, R. Valcke, I. Nijs, and R. Ceulemans, 2005: Grassland species will not necessarily benefit from future elevated air temperatures: a chlorophyll fluorescence approach to study autumn physiology. Physiologia Plantarum, 125(1), pp. 52-63.
Giles, J., 2005: Millennium group nails down the financial value of ecosystems. Nature (London), 434(31 March), pp. 547.
Gill, R.A., H.W. Polley, H.B. Johnson, L.J. Anderson, H. Maherali, and R.B. Jackson, 2002: Nonlinear grassland responses to past and future atmospheric CO2. Nature (London), 417(6886), pp. 279-282.
Gillett, N.P., A.J. Weaver, F.W. Zwiers, and M.D. Flannigan, 2004: Detecting the effect of climate change on Canadian forest fires. Geophysical Research Letters, 31, pp. L18211.
Gitay, H., S. Brown, W. Easterling, and B. Jallow, 2001: Ecosystems and their goods and services. In: Climate Change 2001 - Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel of Climate Change (IPCC) [McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.)]. Cambridge University Press, Cambridge a.o., pp. 237-342.
Gitay, H., A. Suárez, R.T. Watson, and D.J. Dokken, 2002: Climate change and biodiversity. IPCC

Technical Paper, Intergovernmental Panel on Climate Change, Geneva, Switzerland, 77pp.
Gitz, V., and P. Ciais, 2003: Amplifying effects of land-use change on future atmospheric CO2 levels. Global Biogeochemical Cycles, 17(1)
Giupponi, C., M. Ramanzin, E. Strararo, and S. Fuser, 2006: Climate and land use changes, biodiversity and agri-environmental measures in the Belluno province, Italy. Environmental Science and Policy, 9, pp. 163-173.
Gobron, N., B. Pinty, F. Melin, M. Taberner, M.M. Verstraete, A. Belward, T. Lavergne, and J.L. Widlowski, 2005: The state of vegetation in Europe following the 2003 drought. International Journal of remote sensing, 26(9), pp. 2013-2020.
Goldstein, A.H., N.E. Hultman, J.M. Fracheboud, M.R. Bauer, J.A. Panek, M. Xu, Y. Qi, A.B. Guenther, and W. Baugh, 2000: Effects of climate variability on the carbon dioxide, water, and sensible heat fluxes above a ponderosa pine plantation in the Sierra Nevada (CA). Agricultural and Forest Meteorology, 101(2-3), pp. 113-129.
Gonzalez, P., 2001: Desertification and a shift of forest species in the West African Sahel. Climate Research, 17(2), pp. 217-228.
Gopal, B., and M. Chauhan, 2001: South Asian wetlands and their biodiversity: The role of monsoons. In: Biodiversity in Wetlands: Assessment, Function and Conservation. Volume 2 [Gopal, B., W.J. Junk, and J.A. Davis (eds.)]. Backhuys Publishers, Leiden, pp. 257-275.
Gottfried, M., H. Pauli, K. Reiter, and G. Grabherr, 1999: A fine-scaled predictive model for changes in species distribution patterns of high mountain plants induced by climate warming. Diversity and Distribution, 5(5), pp. 241-251.
Goyette, S., O. Brasseur, and M. Beniston, 2003: Application of a new wind gust parameterization: Multiscale case studies performed with the Canadian regional climate model. Journal of Geophysical Research (Atmosphere), 108(D13), pp. art. no.-4374.
Grace, J., F. Berninger, and L. Nagy, 2002: Impacts of climate change on the tree line. Annals of Botany, 90(4), pp. 537-544.
Grace, J., and M. Rayment, 2000: Respiration in the balance. Nature (London), 404(20.Apr.), pp. 819-820.
Graglia, E., R. Julkunen-Tiitto, G.R. Shaver, I.K. Schmidt, S. Jonasson, and A. Michelsen, 2001: Environmental control and intersite variations of phenolics in Betula nana in tundra ecosystems. New Phytologist, 151(1), pp. 227-236.
Graham, R.W., and E.C. Grimm, 1990: Effects of global climate change on the patterns of terrestrial biological communities. Trends in Ecology and Evolution, 5(9), pp. 289-292.
Grant, R.F., W.C. Oechel, and C.L. Ping, 2003: Modelling carbon balances of coastal arctic tundra under changing climate. Global Change Biology, 9(1), pp. 16-36.
Gruber, N., P. Friedlingstein, C.B. Field, R. Valentini, M. Heimann, J.F. Richey, P. Romero, E.D. Schulze, and A. Chen, 2004: The vulnerability of the carbon cycle in the 21st century: An assessment of carbon-climate-human interactions. In: Global Carbon Cycle: Integrating Humans, Climate, and the Natural World [Field, C.B., and M.R. Raupach (eds.)]. Island Press, Washington, D.C., pp. 45-76.
Guinotte, J.M., R.W. Buddemeier, and J.A. Kleypas, 2003: Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. Coral reefs, 22(4), pp. 551-558.
Guinotte, J.M., J. Orr, S. Cairns, A. Freiwald, L. Morgan, and R. George, 2006: Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? Frontiers in Ecology and the Environment, 4(3), pp. 141-146.
Guo, Q.F., 2000: Climate change and biodiversity conservation in Great Plains agroecosystems. Global Environmental Change, 10(4), pp. 289-298.
Gyalistras, D., 2003: Development and validation of a high-resolution monthly gridded temperature and precipitation data set for switzerland (1951-2000). Climate Research, 25(1), pp. 55-83.
Gyalistras, D., and A. Fischlin, 1999: Towards a general method to construct regional climatic scenarios for model-based impacts assessments. Petermanns geographische Mitteilungen, 143(4), pp. 251-264.

Gyalistras, D., H. von Storch, A. Fischlin, and M. Beniston, 1994: Linking GCM-simulated climatic changes to ecosystem models: case studies of statistical downscaling in the Alps. Climate Research, 4(3), pp. 167-189.
Hallock, P., 2005: Global change and modern coral reefs: New opportunities to understand shallow-water carbonate depositional processes. Sedimentary Geology, 175(1-4), pp. 19-33.
Halloy, S.R.P., and A.F. Mark, 2003: Climate-change effects on alpine plant biodiversity: A New Zealand perspective on quantifying the threat. Arctic, Antarctic, and Alpine Research, 35(2), pp. 248-254.
Handel, M.D., and J.S. Risbey, 1992: Reflections on more than a century of climate change research. Climatic Change, 21(2), pp. 91-96.
Hanley, M.E., S. Trofimov, and G. Taylor, 2004: Species-level effects more important than functional group-level responses to elevated CO2: evidence from simulated turves. Functional Ecology, 18(3), pp. 304-313.
Author, 2003: Climate change and biodiversity: synergistic impacts. Adv. Appl. Biodiversity Sci., 4, pp. 1-123.
Hannah, L., G.F. Midgley, G. Hughes, and B. Bomhard, 2005: The view from the Cape: Extinction risk, protected areas and climate change. Bioscience, 55(3), pp. 231-242.
Hannah, L., G.F. Midgley, T. Lovejoy, W.J. Bond, M. Bush, J.C. Lovett, D. Scott, and F.I. Woodward, 2002: Conservation of biodiversity in a changing climate. Conservation Biology, 16(1), pp. 264-268.
Hansen, A.J., R.P. Neilson, V.H. Dale, C.H. Flather, L.R. Iverson, D.J. Currie, S. Shafer, R. Cook, and P.J. Bartlein, 2001: Global change in forests: Responses of species, communities, and biomes. Bioscience, 51(9), pp. 765-779.
Hanson, P.J., and J.F. Weltzin, 2000: Drought disturbance from climate change: response of United States forests. Science of the Total Environment, 262(3), pp. 205-220.
Harden, J.W., S.E. Trumbore, B.J. Stocks, A. Hirsch, S.T. Gower, K.P. O'Neill, and E.S. Kasischke, 2000: The role of fire in the boreal carbon budget. Global Change Biology, 6(Suppl. 1), pp. 174-184.
Harding, R., P. Kuhry, T.R. Christensen, M.T. Sykes, R. Dankers, and S. van der Linden, 2002: Climate feedbacks at the tundra-taiga interface. Ambio, Spec No 12, pp. 47-55.
Hardy, J.T., 2003: Climate change causes, effects and solutions. Wiley, Chichester, 247pp.
Harmens, H., P.D. Williams, S.L. Peters, M.T. Bambrick, A. Hopkins, and T.W. Ashenden, 2004: Impacts of elevated atmospheric CO2 and temperature on plant community structure of a temperate grassland are modulated by cutting frequency. Grass & Forage Science, 59(2), pp. 144-156.
Harou, P.A., 2002: What is the role of markets in altering the sensitivity of arid land systems to perturbation. In: Global desertification. Do humans cause deserts? [Reynolds, J.F., and D.M. Stafford-Smith (eds.)]. Dahlem University Press, Berlin, Germany, pp. 253-274.
Harper, C.W., J.M. Blair, P.A. Fay, A.K. Knapp, and J.D. Carlisle, 2005: Increased rainfall variability and reduced rainfall amount decreases soil CO2 flux in a grassland ecosystem. Global Change Biology, 11(2), pp. 322-334.
Harrison, P.A., P.M. Berry, N. Butt, and M. New, 2006: Modelling climate change impacts on species' distributions at the European scale: implications for conservation policy. Environmental Science and Policy, 9, pp. 116-128.
Harrison, S.P., and A.I. Prentice, 2003: Climate and CO2 controls on global vegetation distribution at the last glacial maximum: analysis based on palaeovegetation data, biome modelling and palaeoclimate simulations. Global Change Biology, 9(7), pp. 983-1004.
Hartig, E.K., V. Gornitz, A. Kolker, F.K. Muschake, and D. Fallon, 2002: Anthropogenic and climatic change impacts on salt marshes of Jamaica Bay, New York City. Wetlands, 22(1), pp. 71-89.
Hassan, R., R. Scholes, and N. Ash (eds.), 2005: Ecosystems and human well-being - volume 1: current state & trends. Island Press, Washington, DC, 917pp.
Hassol, S.J. (ed.), 2004a: Impacts of a warming Arctic: Arctic climate impact assessment - Highlights.

Cambridge Univ. Press, Cambridge, UK, 20pp.
Hassol, S.J. (ed.), 2004b: Impacts of a warming Arctic: Arctic climate impact assessment - Overview report. Cambridge Univ. Press, Cambridge, UK, 146pp.
Hastings, S.J., W.C. Oechel, and A. Muhlia-Melo, 2005: Diurnal, seasonal and annual variation in the net ecosystem CO2 exchange of a desert shrub community (Sarcocaulescent) in Baja California, Mexico. Global Change Biology, 11(6), pp. 927-939.
Haugaasen, T., J. Barlow, and C.A. Peres, 2003: Surface wildfires in central Amazonia: short-term impact on forest structure and carbon loss. Forest Ecology and Management, 179(1-3), pp. 321-331.
Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville, 2004: Emissions pathways, climate change, and impacts on California. Proceedings of the National Academy of sciences of the United States of America, 101(34), pp. 12422-12427.
Heath, J., E. Ayres, M. Possell, R.D. Bardgett, H.I.J. Black, H. Grant, P. Ineson, and G. Kerstiens, 2005: Rising atmospheric CO2 reduces sequestration of root-derived soil carbon. Science, 309(5741), pp. 1711-1713.
Hein, L., and N. Ridder, 2007: Desertification in the Sahel: a reinterpretation. Global Change Biology, 12, pp. 8(in press).
Held, I.M., T.L. Delworth, J. Lu, K.L. Findell, and T.R. Knutson, 2005: Simulation of Sahel drought in the 20th and 21st centuries.
Proceedings of the National Academy of sciences of the United States of America, 102(50), pp. 17891-17896.
Helmuth, B., C.D.G. Harley, P.M. Halpin, M. O'Donnell, G.E. Hofmann, and C.A. Blanchette, 2002: Climate change and latitudinal patterns of intertidal thermal stress. Science, 298(5595), pp. 1015-1017.
Hess, J.C., C.A. Scott, G.L. Hufford, and M.D. Fleming, 2001: El Niño and its impact on fire weather conditions in Alaska. International Journal Of Wildland Fire, 10(1), pp. 1-13.
Hetherington, A.M., and F.I. Woodward, 2003: The role of stomata in sensing and driving environmental change. Nature (London), 424(6951), pp. 901-908.
Heywood, V.H., and R.T. Watson (eds.), 1995: Global biodiversity assessment. Cambridge University Press, Cambridge, 1140pp.
Hicke, J.A., G.P. Asner, E.S. Kasischke, N.H.F. French, J.T. Randerson, G.J. Collatz, B.J. Stocks, C.J. Tucker, S.O. Los, and C.B. Field, 2003: Postfire response of North American boreal forest net primary productivity analyzed with satellite observations. Global Change Biology, 9(8), pp. 1145-1157.
Hiernaux, P., and M.D. Turner, 2002: The influence of farmer and pastoral management practices on desertification processes in the Sahel. In: Global desertification. Do humans cause deserts? [Reynolds, J.F., and D.M. Stafford-Smith (eds.)]. Dahlem University Press, Berlin, Germany, pp. 135-148.
Hilbert, D.W., M. Bradford, T. Parker, and D.A. Westcott, 2004: Golden bowerbird (Prionodura newtonia) habitat in past, present and future climates: predicted extinction of a vertebrate in tropical highlands due to global warming. Biological Conservation, 116(3), pp. 367.
Hilbert, D.W., B. Ostendorf, and M.S. Hopkins, 2001: Sensitivity of tropical forests to climate change in the humid tropics of north Queensland. Austral Ecology, 26(6), pp. 590-603.
Hinzman, L., N. Bettez, W. Bolton, F. Chapin, M. Dyurgerov, C. Fastie, B. Griffith, R. Hollister, A. Hope, H. Huntington, A. Jensen, G. Jia, T. Jorgenson, D. Kane, D. Klein, G. Kofinas, A. Lynch, A. Lloyd, A. McGuire, F. Nelson, W. Oechel, T. Osterkamp, C. Racine, V. Romanovsky, R. Stone, D. Stow, M. Sturm, C. Tweedie, G. Vourlitis, M. Walker, D. Walker, P. Webber, J. Welker, K. Winker, and K. Yoshikawa, 2005: Evidence and implications of recent climate change in northern Alaska and other Arctic regions. Climatic Change, 72(3), pp. 251-298.
Hodar, J.A., and R. Zamora, 2004: Herbivory and climatic warming: a Mediterranean outbreaking

caterpillar attacks a relict, boreal pine species. Biodiversity and Conservation, 13(3), pp. 493-500.
Hoegh-Guldberg, O., 1999: Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research, 50(8), pp. 839-866.
Hoegh-Guldberg, O., 2004: Coral reefs in a century of rapid environmental change. Symbiosis, 37(1-3), pp. 1-31.
Hoegh-Guldberg, O., 2005: Low coral cover in a high-CO2 world. Journal of Geophysical Research (Oceans), 110(Aug.), pp. C09S06.
Hoegh-Guldberg, O., H. Hoegh-Guldberg, D.K. Stout, H. Cesar, and A. Timmerman, 2000: Pacific in peril - Biological, economic and social impacts of climate change on Pacific coral reefs. Greenpeace.
Hoffmann, W.A., and R.B. Jackson, 2000: Vegetation-climate feedbacks in the conversion of tropical savanna to grassland. Journal of Climate, 13(9), pp. 1593-1602.
Hogg, E.H., and A.G. Schwarz, 1997: Regeneration of planted conifers across climatic moisture gradients on the Canadian prairies: implications for distribution and climate change. Journal of Biogeography, 24(4), pp. 527-534.
Holligan, P.M., E. Fernandez, J. Aiken, W.M. Balch, P. Boyd, P.H. Burkill, M. Finch, S.B. Groom, G. Malin, K. Muller, D.A. Purdie, C. Robinson, C.C. Trees, S.M. Turner, and P. Vanerwal, 1993: A biogeochemical study of the coccolithophore, Emiliania huxleyi, in the North-Atlantic. Global Biogeochemical Cycles, 7(4), pp. 879-900.
Holman, I.P., R.J. Nicholls, P.M. Berry, P.A. Harrison, E. Audsley, S. Shackley, and M.D.A. Rounsevell, 2005a: A regional, multi-sectoral and integrated assessment of the impacts of climate and socio-economic change in the UK - Part II. Results. Climatic Change, 71(1), pp. 43-73.
Holman, I.P., M.D.A. Rounsevell, S. Shackley, P.A. Harrison, R.J. Nicholls, P.M. Berry, and E. Audsley, 2005b: A regional, multi-sectoral and integrated assessment of the impacts of climate and socio-economic change in the UK - Part I. Methodology. Climatic Change, 71(1), pp. 9-41.
Holmgren, M., and M. Scheffer, 2001: El Nino as a window of opportunity for the restoration of degraded arid ecosystems. Ecosystems, 4(2), pp. 151-159.
Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.), 2001: Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel of Climate Change (IPCC). Cambridge University Press, Cambridge a.o., 881pp.
Houghton, R.A., 2003a: Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850- 2000. Tellus - Series B: Chemical and physical meteorology, 55(2), pp. 378-390.
Houghton, R.A., 2003b: Why are estimates of the terrestrial carbon balance so different? Global Change Biology, 9(4), pp. 500-509.
Hsieh, C.I., G. Kiely, A. Birkby, and G. Katul, 2005: Photosynthetic responses of a humid grassland ecosystem to future climate perturbations. Advances In Water Resources, 28, pp. 910-916.
Huber, U.M., H.K.M. Bugmann, and M.A. Reasoner (eds.), 2005: Global change and mountain regions: an overview of current knowledge. Springer, Berlin, 650pp.
Huelber, K., M. Gottfried, H. Pauli, K. Reiter, M. Winkler, and G. Grabherr, 2006: Phenological responses of snowbed species to snow removal dates in the Central Alps: Implications for climate warming. Arctic Antarctic and Alpine Research, 38(1), pp. 99-103.
Hughes, L., 2003: Climate change and Australia: Trends, projections and impacts. Austral Ecology, 28(4), pp. 423-443.
Hughes, L., E.M. Cawsey, and M. Westoby, 1996: Climatic range sizes of Eucalyptus species in relation to future climate change. Global Ecology and Biogeography Letters, 5(1), pp. 23-29.
Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Kleypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden, 2003: Climate change, human impacts, and the resilience of coral reefs. Science, 301(5635), pp. 929-933.
Hulme, M., 2001: Climatic perspectives on Sahelian desiccation: 1973-1998.

Global Environmental Change, 11(1), pp. 19-29.
Hulme, M., J. Mitchell, W. Ingram, J. Lowe, T. Johns, M. New, and D. Viner, 1999: Climate change scenarios for global impacts studies. Global Environmental Change, 9(Supplement 1), pp. S3-S19.
Hungate, B.A., C.H. Jaeger Iii, G. Gamara, F.S. Chapin Iii, and C.B. Field, 2000: Soil microbiota in two annual grasslands: responses to elevated atmospheric CO2. Oecologia, 124(4), pp. 589-598.
Hungate, B.A., D.W. Johnson, P. Dukstra, G. Hymus, P. Stiling, J.P. Megonigal, A.L. Pagel, J.L. Moan, F. Day, J. Li, C.R. Hinkle, and B.G. Drake, 2006: Nitrogen cycling during seven years of atmospheric CO2 enrichment in a scrub oak woodland. Ecology, 87(1), pp. 26-40.
Hurrell, J.W., and H. van Loon, 1997: Decadal variations in climate associated with the North Atlantic oscillation. Climatic Change, 36, pp. 301-326.
Huxman, T.E., B.P. Wilcox, D.D. Breshears, R.L. Scott, K.A. Snyder, E.E. Small, K. Hultine, W.T. Pockman, and R.B. Jackson, 2005: Ecohydrological implications of woody plant encroachment. Ecology, 86(2), pp. 308-319.
iLeaps (ed.), 2005: Title. IGBP report No. 54, International Geosphere and Biosphere Program Secretariat, Stockholm, Sweden, 52pp.
Inkley, D.B., M.G. Anderson, A.R. Blaustein, V.R. Burkett, B. Felzer, B. Griffith, J. Price, and T.L. Root, 2004: Global climate change and wildlife in North America. The Wildlife Society, Bethesda, Maryland, 34pp.
Inouye, D.W., B. Barr, K.B. Armitage, and B.D. Inouye, 2000: Climate change is affecting altitudinal migrants and hibernating species.
Proceedings of the National Academy of sciences of the United States of America, 97(4), pp. 1630-1633.
IPCC-TGCIA, 1999: Guidelines on the use of scenario data for climate impact and adaptation assessment. Prepared by Carter, T.R., Hulme, M. & M. Lal, Intergovernmental Panel on Climate Change (IPCC) - Task Group on Scenarios for Climate Impact Assessment (TGCIA), Norwich, UK, Hamburg, Germany, and New York, USA, 69pp.
Irland, L.C., 2000: Ice storms and forest impacts. Science of the Total Environment, 262(3), pp. 231-242.
Iverson, L.R., and A.M. Prasad, 2002: Potential redistribution of tree species habitat under five climate change scenarios in the eastern US. Forest Ecology and Management, 155(1-3), pp. 205-222.
Iverson, L.R., M.W. Schwartz, and A.M. Prasad, 2004: How fast and far might tree species migrate in the eastern United States due to climate change? Global Ecology and Biogeography, 13(3), pp. 209-219.
Izaurralde, R.C., A.M. Thomson, N.J. Rosenberg, and R.A. Brown, 2005: Climate change impacts for the conterminous USA: An integrated assessment - Part 6. Distribution and productivity of unmanaged ecosystems. Climatic Change, 69(1), pp. 107-126.
Jackson, D.A., and N.E. Mandrak, 2002: Changing fish biodiversity: Predicting the loss of cyprinid biodiversity due to global climate change. In: Fisheries in a changing climate. [McGinn, N.A. (ed.)]. American Fisheries Society Symposium 32. August 20-21, Phoenix, Arizona. American Fisheries Society, Bethesda, MD, USA, pp. 89-98.
Jackson, R.B., J.L. Banner, E.G. Jobbagy, W.T. Pockman, and D.H. Wall, 2002: Ecosystem carbon loss with woody plant invasion of grasslands. Nature (London), 418(6898), pp. 623-626.
Jain, R., 2003: Sustainable development: differing views and policy alternatives.
Clean Technologies and Environmental Policy, 4(4), pp. 197-198.
Jankowski, T., D.M. Livingstone, H. Bührer, R. Forster, and P. Niederhaser, 2006: Consequences of the 2003 European heat wave for lake temperature profiles, thermal stability and hypolimnetic oxygen depletion: Implications for a warmer world. Limnology and Oceanography, 51(2), pp. 815-819.
Jansson, R., 2003: Global patterns in endemism explained by past climatic change. Proceedings of the Royal Society of London Series B-Biological Sciences, 270(1515), pp. 583-590.
Jasienski, M., S.C. Thomas, and F.A. Bazzaz, 1998: Blaming the trees: a critique of research on forest responses to high CO2. Trends in Ecology and Evolution, 13(10 Oct.), pp. 427.

Jasper, K., P. Calanca, D. Gyalistras, and J. Fuhrer, 2004: Differential impacts of climate change on the hydrology of two alpine river basins. Climate Research, 26(2), pp. 113-129.

Jenkins, M., 2003: Prospects for biodiversity. Science, 302(5648), pp. 1175-1177.

Johansen, R.J., 2001: Impacts of fire on biological soil crusts. In: Biological soil crusts structure, function, and management [Belnap, J. (ed.)]. Springer, Berlin, pp. 386-397.

Johnson, W.C., B.V. Millett, T. Gilmanov, R.A. Voldseth, G.R. Guntenspergen, and D.E. Naugle, 2005: Vulnerability of northern prairie wetlands to climate change. Bioscience, 55(10), pp. 863-872.

Jolly, W.M., M. Dobbertin, N.E. Zimmermann, and M. Reichstein, 2005: Divergent vegetation growth responses to the 2003 heat wave in the Swiss Alps. Geophysical Research Letters, 32(L18409), pp. L18409, doi:10.1029/2005GL023252.

Jompa, J., and L.J. McCook, 2003: Coral-algal competition: macroalgae with different properties have different effects on corals. Marine Ecology. Progress Series, 258, pp. 87-95.

Jones, M.B., and A. Donnelly, 2004: Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO_2. New Phytologist, 164(3), pp. 423-439.

Joos, F., and I.C. Prentice, 2004: A paleo-perspective on changes in atmospheric CO_2 and climate. In: Global Carbon Cycle: Integrating Humans, Climate, and the Natural World [Field, C.B., and M.R. Raupach (eds.)]. Island Press, Washington, D.C., pp. 165-186.

Juday, G.P., 2005: Forests, land management, and agriculture. In: Arctic climate impact assessment (ACIA) - scientific report [Symon, C., L. Arris, and B. Heal (eds.)]. Cambridge Univ. Press, Cambridge, UK, pp. 781-862.

Jump, A.S., and J. Penuelas, 2005: Running to stand still: adaptation and the response of plants to rapid climate change. Ecology Letters, 8(9), pp. 1010-1020.

Kabat, P., M. Claussen, P.A. Dirmeyer, J.H.C. Gash, L.B. Deguenni, M. Meybeck, R.A.S. Pielke, C.J. Vörösmarty, R.W.A. Hutjes, and S. Lütkemeier (eds.), 2004: Vegetation, water, humans and the climate: a new perspective on an interactive system. Springer, Heidelberg, 566pp.

Kajimoto, T., H. Daimaru, T. Okamoto, T. Otani, and H. Onodera, 2004: Effects of snow avalanche disturbance on regeneration of subalpine Abies mariesii forest, northern Japan. Arctic, Antarctic, and Alpine Research, 36(4), pp. 436-445.

Kankaanpää, S., and T. Carter, 2004: Construction of European forest land use scenarios for the 21st century. The Finnish Environment 7, Finnish Environment Institute, Helsinki, Finland, 60pp.

Kaplan, J.O., N.H. Bigelow, I.C. Prentice, S.P. Harrison, P.J. Bartlein, T.R. Christensen, W. Cramer, N.V. Matveyeva, A.D. McGuire, D.F. Murray, V.Y. Razzhivin, B. Smith, D.A. Walker, P.M. Anderson, A.A. Andreev, L.B. Brubaker, M.E. Edwards, and A.V. Lozhkin, 2003: Climate change and Arctic ecosystems: 2. Modeling, paleodata-model comparisons, and future projections. Journal of Geophysical Research (Atmosphere), 108(D19)

Kappelle, M., M.M.I. Van Vuuren, and P. Baas, 1999: Effects of climate change on biodiversity: a review and identification of key research issues. Biodiversity and Conservation, 8(10), pp. 1383-1397.

Karjalainen, T., A. Pussinen, J. Liski, G.J. Nabuurs, M. Erhard, T. Eggers, M. Sonntag, and G.M.J. Mohren, 2002: An approach towards an estimate of the impact of forest management and climate change on the European forest sector carbon budget: Germany as a case study. Forest Ecology and Management, 162(1), pp. 87-103.

Karlsson, J., A. Jonsson, and M. Jansson, 2005: Productivity of high-latitude lakes: climate effect inferred from altitude gradient. Global Change Biology, 11(5), pp. 710-715.

Karnosky, D.F., 2003: Impacts of elevated atmospheric CO_2 on forest trees and forest ecosystems: knowledge gaps. Environment International, 29(2-3), pp. 161-169.

Karnosky, D.F., D.R. Zak, K.S. Pregitzer, C.S. Awmack, J.G. Bockheim, R.E. Dickson, G.R. Hendrey, G.E. Host, J.S. King, B.J. Kopper, E.L. Kruger, M.E. Kubiske, R.L. Lindroth, W.J. Mattson, E.P. McDonald, A. Noormets, E. Oksanen, W.F.J. Parsons, K.E. Percy, G.K. Podila, D.E. Riemenschneider, P. Sharma, R. Thakur, A. Sober, J. Sober, W.S. Jones, S. Anttonen, E. Vapaavuori, B. Mankovska, W. Heilman, and J.G. Isebrands, 2003: Tropospheric O-3 moderates

responses of temperate hardwood forests to elevated CO2: a synthesis of molecular to ecosystem results from the Aspen FACE project. Functional Ecology, 17(3), pp. 289-304.
Kasischke, E.S., N.L. Christensen Jr, and B.J. Stocks, 1995: Fire, global warming, and the carbon balance of boreal forests. Ecological Applications, 5, pp. 437-451.
Kasischke, E.S., E.J. Hyer, P.C. Novelli, L.P. Bruhwiler, N.H.F. French, A.I. Sukhinin, J.H. Hewson, and B.J. Stocks, 2005: Influences of boreal fire emissions on Northern Hemisphere atmospheric carbon and carbon monoxide. Global Biogeochemical Cycles, 19(1)
Kasischke, E.S., and B.J. Stocks (eds.), 2000: Fire, climate change and carbon cycling in the boreal forest. Springer-Verlag, New York, 461pp.
Kates, R.W., 2000: Cautionary tales: Adaptation and the global poor. Climatic Change, 45(1), pp. 5-17.
Keddy, P.A., 2000: Wetland ecology: principles and conservation. Cambridge University Press, Cambridge, U.K., 614pp.
Keeley, J.E., 2002: Fire management of California shrubland landscapes. Environmental Management, 29(3), pp. 395-408.
Keller, A.A., and G. Klein-Macphee, 2000: Impact of elevated temperature on the growth, survival, and trophic dynamics of winter flounder larvae: a mesocosm study. Canadian Journal of Fisheries and Aquatic Sciences, 57(12), pp. 2382-2392.
Keller, F., S. Goyette, and M. Beniston, 2005: Sensitivity analysis of snow cover to climate change scenarios and their impact on plant habitats in alpine terrain. Climatic Change, 72(3), pp. 299-319.
Keller, J.K., J.R. White, S.D. Bridgham, and J. Pastor, 2004: Climate change effects on carbon and nitrogen mineralization in peatlands through changes in soil quality. Global Change Biology, 10(7), pp. 1053-1064.
Kennett, S.A., 2002: FORUM national policies for biosphere greenhouse gas management: issues and opportunities. Environmental Management, 30(5), pp. 595-608.
Keppler, F., J.T.G. Hamilton, M. Brass, and T. Rockmann, 2006: Methane emissions from terrestrial plants under aerobic conditions. Nature (London), 439(7073), pp. 187-191.
Kerr, J., and L. Packer, 1998: The impact of climate change on mammal diversity in Canada. Environmental Monitoring and Assessment, 49(2-3), pp. 263-270.
Kienast, F., O. Wildi, and B. Brzeziecki, 1998: Potential impacts of climate change on species richness in mountain forests - an ecological risk assessment. Biological Conservation, 83(3), pp. 291-305.
Kimball, B.A., K. Kobayashi, and M. Bindi, 2003: Responses of agricultural crops to free-air CO2 enrichment. Advances in Agronomy, 77, pp. 293-368.
Kimball, B.A., J. Zhu, L. Cheng, K. Kobayashi, and M. Bindi, 2002: Responses of agricultural crops of free-air CO2 enrichment. Journal of Applied Ecology, 13(10), pp. 1323-1338.
King, J.A., R.I. Bradley, R. Harrison, and A.D. Carter, 2004a: Carbon sequestration and saving potential associated with changes to the management of agricultural soils in England. Soil Use and Management, 20(4), pp. 394-402.
King, J.S., P.J. Hanson, E. Bernhardt, P. Deangelis, R.J. Norby, and K.S. Pregitzer, 2004b: A multiyear synthesis of soil respiration responses to elevated atmospheric CO2 from four forest FACE experiments. Global Change Biology, 10(6), pp. 1027-1042.
Kirschbaum, M., and A. Fischlin, 1996: Climate change impacts on forests. In: Climate change 1995 - Impacts, adaptations and mitigation of climate change: scientific-technical analysis. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel of Climate Change. [Watson, R., M.C. Zinyowera, and R.H. Moss (eds.)]. Cambridge University Press, Cambridge a.o., pp. 95-129.
Kitayama, K., 1996: Climate of the summit region of Mount Kinabalu (Borneo) in 1992, an El Nino year. Mountain research and development, 16(1), pp. 65-75.
Klanderud, K., 2005: Climate change effects on species interactions in an alpine plant community. Journal of Ecology, 93(1), pp. 127-137.
Klanderud, K., and O. Totland, 2005: Simulated climate change altered dominance hierarchies and diversity of an alpine biodiversity hotspot. Ecology, 86(8), pp. 2047-2054.
Kleypas, J.A., R.W. Buddemeier, D. Archer, J.P. Gattuso, C. Langdon, and B.N. Opdyke, 1999:

Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science, 284(2.Apr.), pp. 118-120.
Kleypas, J.A., R.W. Buddemeier, C.M. Eakin, J.P. Gattuso, J. Guinotte, O. Hoegh-Guldberg, R. Iglesias-Prieto, P.L. Jokiel, C. Langdon, W. Skirving, and A.E. Strong, 2005: Comment on "Coral reef calcification and climate change: The effect of ocean warming". Geophysical Research Letters, 32(8)
Kleypas, J.A., R.W. Buddemeier, and J.P. Gattuso, 2001: The future of coral reefs in an age of global change. International Journal of Earth Science, 90(2), pp. 426-437.
Kleypas, J.A., and C. Langdon, 2002: Overview of CO2-induced changes in seawater chemistry. In: World Coral Reefs in the New Millenium: Bridging Research and Management for Sustainable Development. [Moosa, M.K., S. Soemodihardjo, A. Soegiarto, K. Romimohtarto, A. Nontji, and S. Suharsono (eds.)]. 2. Proc. 9th Int. Coral Reef Sym., Bali, Indonesia;23-27 Oct. 2000. Ministry of Environment, Indonesian Institute of Sciences, International Society for Reef Studies, pp. 1085-1089.
Kling, J., K. Hayhoe, L.B. Johnsoin, J.J. Magnuson, S. Polasky, S.K. Robinson, B.J. Shuter, M.M. Wander, D.J. Wuebbles, and D.R. Zak, 2003: Confronting climate change in the Great Lakes region: Impacts on our communities and ecosystems. Union of Concerned Scientists and the Ecological Society of America, Cambridge, MA, USA and Washington, D.C., 92pp.
Kohler, P., F. Joos, S. Gerber, and R. Knutti, 2005: Simulated changes in vegetation distribution, land carbon storage, and atmospheric CO2 in response to a collapse of the North Atlantic thermohaline circulation. Climate Dynamics, 25(7-8), pp. 689-708.
Koop, K., D. Booth, A. Broadbent, J. Brodie, D. Bucher, D. Capone, J. Coll, W. Dennison, M. Erdmann, P. Harrison, O. Hoegh-Guldberg, P. Hutchings, G.B. Jones, A.W.D. Larkum, J. O'Neil, A. Steven, E. Tentori, S. Ward, J. Williamson, and D. Yellowlees, 2001: ENCORE: The effect of nutrient enrichment on coral reefs. Synthesis of results and conclusions. Marine Pollution Bulletin, 42(2), pp. 91-120.
Koren, I., Y.J. Kaufman, L.A. Remer, and J.V. Martins, 2004: Measurement of the effect of Amazon smoke on inhibition of cloud formation. Science, 303(5662), pp. 1342-1345.
Korner, C., 2003a: Ecological impacts of atmospheric CO2 enrichment on terrestrial ecosystems. Philosophical Transactions of the Royal Society of London - Series A, 361(1810), pp. 2023-2041.
Korner, C., 2003b: Slow in, rapid out - Carbon flux studies and Kyoto targets. Science, 300(5623), pp. 1242-1243.
Korner, C., 2004: Through enhanced tree dynamics carbon dioxide enrichment may cause tropical forests to lose carbon. Philosophical Transactions of the Royal Society of London - Series A, 359(1443), pp. 493-498.
Körner, C., 1998: Worldwide positions of alpine treelines and their causes. In: The impacts of climate variability on forests [Beniston, M., and J.L. Innes (eds.)]. Springer, Berlin, Germany, pp. 221-229.
Körner, C., 1999: Alpine plant life - functional plant ecology of high mountain ecosystems. Springer, Berlin, 343pp.
Körner, C., 2000: Why are there global gradients in species richness? Mountains might hold the answer. Trends in Ecology and Evolution, 15(12.Dec.), pp. 513-514.
Körner, C., 2007: Plant CO2 responses: an issue of definition, time and resource supply. New Phytologist
Körner, C., R. Asshoff, O. Bignucolo, S. Hättenschwiler, S.G. Keel, S. Pel´ez-Riedl, S. Pepin, R.T.W. Siegwolf, and G. Zotz, 2005a: Carbon flux and growth in mature deciduous forest trees exposed to elevated CO2. Science, 309(5739), pp. 1360-1362.
Korner, C., and J. Paulsen, 2004: A world-wide study of high altitude treeline temperatures. Journal of Biogeography, 31(5), pp. 713-732.
Körner, C., D. Sarris, and D. Christodoulakis, 2005b: Long-term increase in climatic dryness in the East-Mediterranean as evidenced for the island of Samos. Regional Environmental Change, 5(1), pp. 27-36.
Krauchi, N., P. Brang, and W. Schonenberger, 2000: Forests of mountainous regions: gaps in

knowledge and research needs. Forest Ecology and Management, 132(1), pp. 73-82.
Kremen, C., 2005: Managing ecosystem services: what do we need to know about their ecology? Ecology Letters, 8(5), pp. 468-479.
Kurz, W.A., and M.J. Apps, 1999: A 70-year retrospective analysis of carbon fluxes in the Canadian Forest Sector. Ecological Applications, 9(2), pp. 526-547.
Lake, J.C., and M.R. Leishman, 2004: Invasion success of exotic plants in natural ecosystems: the role of disturbance, plant attributes and freedom from herbivores. Biological Conservation, 117(2), pp. 215-226.
Lake, P.S., M.A. Palmer, P. Biro, J. Cole, A.P. Covich, C. Dahm, J. Gibert, W. Goedkoop, K. Martens, and J. Verhoeven, 2000: Global change and the biodiversity of freshwater ecosystems: Impacts on linkages between above-sediment and sediment biota. Bioscience, 50(12), pp. 1099-1107.
Lal, R., 2003: Offsetting global CO2 emissions by restoration of degraded soils and intensification of world agriculture and forestry. Land Degradation & Development, 14(3), pp. 309-322.
Lal, R., 2004: Soil carbon sequestration to mitigate climate change. Geoderma, 123(1-2), pp. 1-22.
Lambin, E.F., H.J. Geist, and E. Lepers, 2003: Dynamics of land-use and land-cover change in tropical regions. Annual Review of Ecology Evolution and Systematics, 28, pp. 205-241.
Lambin, E.F., B.L. Turner, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X.B. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skanes, W. Steffen, G.D. Stone, U. Svedin, T.A. Veldkamp, and C.X.J.C. Vogel, 2001: The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change, 11(4), pp. 261-269.
Langdon, C., W.S. Broecker, D.E. Hammond, E. Glenn, K. Fitzsimmons, S.G. Nelson, T.H. Peng, I. Hajdas, and G. Bonani, 2003: Effect of elevated CO2 on the community metabolism of an experimental coral reef. Global Biogeochemical Cycles, 17(1), pp. 1011.
Langenfelds, R.L., R.J. Francey, B.C. Pak, L.P. Steele, J. Lloyd, C.M. Trudinger, and C.E. Allison, 2002: Interannual growth rate variations of atmospheric CO2 and its d 13C, H2, CH4, and CO between 1992 and 1999 linked to biomass burning. Global Biogeochemical Cycles, 16(3), pp. 1048.
Langmead, O., and C. Sheppard, 2007: Effect of repeated climatic impacts on a coral community: a simulation study. Global Change Biology, pp. submitted.
Lara, A., R. Villalba, A. Wolodarsky-Franke, J.C. Aravena, B.H. Luckman, and E. Cuq, 2005: Spatial and temporal variation in Nothofagus pumilio growth at tree line along its latitudinal range (35 degrees 40 '-55 degrees S) in the Chilean Andes. Journal of Biogeography, 32(5), pp. 879-893.
Lauenroth, W.K., H.E. Epstein, J.M. Paruelo, I.C. Burke, M.R. Aguiar, and O.E. Sala, 2004: Potential effects of climate change on the temperate zones of North and South America. Revista Chilena De Historia Natural, 77(3), pp. 439-453.
Lavoie, L., and L. Sirois, 1998: Vegetation changes caused by recent fires in the northern boreal forest of eastern Canada. Journal of Vegetation Science, 9(4), pp. 483-492.
Lavorel, S., 1999: Ecological diversity and resilience of Mediterranean vegetation to disturbance. Diversity and Distribution, 5(1-2), pp. 3-13.
Lawton, R.O., U.S. Nair, R.A. Pielke Sr, and R.M. Welch, 2001: Climatic impact of tropical lowland deforestation on nearby montane cloud forests. Science, 294(19.Oct.), pp. 584-587.
Le Maitre, D.C., D.M. Richardson, and R.A. Chapman, 2004: Alien plant invasions in South Africa: driving forces and the human dimension. South African Journal of Science, 100(1), pp. 103-112.
Le Roux, P.C., M.A. McGeoch, M.J. Nyakatya, and S.L. Chown, 2005: Effects of a short-term climate change experiment on a sub-Antarctic keystone plant species. Global Change Biology, 11(10), pp. 1628-1639.
Leemans, R., and B. Eickhout, 2004: Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. Global Environmental Change, 14(3), pp. 219-228.
Leemans, R., B. Eickhout, B. Strengers, L. Bouwman, and M. Schaeffer, 2002: The consequences of uncertainties in land use, climate and vegetation responses on the terrestrial carbon.

Science In China Series C - Life Sciences, 45, pp. 126-141.

Lehodey, P., F. Chai, and J. Hampton, 2003: Modelling climate-related variability of tuna populations from a coupled ocean-biogeochemical-populations dynamics model. Fisheries Oceanography, 12(4-5), pp. 483-494.

Lejeune, O., M. Tlidi, and R. Lefever, 2004: Vegetation spots and stripes: dissipative structures in arid landscapes. International Journal of Quantum Chemistry, 98(2), pp. 261-271.

Lelieveld, J., H. Berresheim, S. Borrmann, P.J. Crutzen, F.J. Dentener, H. Fischer, J. Feichter, P.J. Flatau, J. Heland, R. Holzinger, R. Korrmann, M.G. Lawrence, Z. Levin, K.M. Markowicz, N. Mihalopoulos, A. Minikin, V. Ramanathan, M. de Reus, G.J. Roelofs, H.A. Scheeren, J. Sciare, H. Schlager, M. Schultz, P. Siegmund, B. Steil, E.G. Stephanou, P. Stier, M. Traub, C. Warneke, J. Williams, and H. Ziereis, 2002: Global air pollution crossroads over the Mediterranean. Science, 298(5594), pp. 794-799.

Lenihan, J.M., C. Daly, D. Bachelet, and R.P. Neilson, 1998: Simulating broad-scale fire severity in a Dynamic Global Vegetation Model. Northwest Scientist, 72, pp. 91-103.

Lenihan, J.M., R. Drapek, D. Bachelet, and R.P. Neilson, 2003: Climate change effects on vegetation distribution, carbon, and fire in California. Ecological Applications, 13(6), pp. 1667.

Lepers, E., E.F. Lambin, A.C. Janetos, R. Defries, F. Achard, N. Ramankutty, and R.J. Scholes, 2005: A synthesis of information on rapid land-cover change for the period 1981-2000. Bioscience, 55(2), pp. 115-124.

Leuzinger, S., G. Zotz, R. Asshoff, and C. Korner, 2005: Responses of deciduous forest trees to severe drought in Central Europe. Tree Physiology, 25(6), pp. 641-650.

Levy, P.E., M.G.R. Cannell, and A.D. Friend, 2004: Modelling the impact of future changes in climate, CO2 concentration and land use on natural ecosystems and the terrestrial carbon sink. Global Environmental Change, 14(1), pp. 21-30.

Lexer, M.J., K. Honninger, H. Scheifinger, C. Matulla, N. Groll, and H. Kromp-Kolb, 2000: The sensitivity of central European mountain forests to scenarios of climatic change: Methodological frame for a large-scale risk assessment. Silva Fennica, 34(2), pp. 113-129.

Lexer, M.J., K. Honninger, H. Scheifinger, C. Matulla, N. Groll, H. Kromp-Kolb, K. Schadauer, F. Starlinger, and M. Englisch, 2002: The sensitivity of Austrian forests to scenarios of climatic change: a large-scale risk assessment based on a modified gap model and forest inventory data. Forest Ecology and Management, 162(1), pp. 53-72.

Li, C., M.D. Flannigan, and I.G.W. Corns, 2000: Influence of potential climate change on forest landscape dynamics of west-central Alberta. Canadian Journal of Forest Research, 30(12), pp. 1905-1912.

Li, S.G., J. Asanuma, W. Eugster, A. Kotani, J.J. Liu, T. Urano, T. Oikawa, G. Davaa, D. Oyunbaatar, and M. Sugita, 2005: Net ecosystem carbon dioxide exchange over grazed steppe in central Mongolia. Global Change Biology, 11(11), pp. 1941-1955.

Lichter, J., S.H. Barron, C.E. Bevacqua, A.C. Finzi, K.F. Irving, E.A. Stemmler, and W.H. Schlesinger, 2005: Soil carbon sequestration and turnover in a pine forest after six year of atmospheric CO2 enrichment. Ecology, 86(7), pp. 1835-1847.

Lie, E., H.J.S. Larsen, S. Larsen, G.M. Johansen, A.E. Derocher, N.J. Lunn, R.J. Norstrom, O. Wiig, and J.U. Skaare, 2005: Does high organochlorine (OC) exposure impair the resistance to infection in polar bears (Ursus maritimus)? Part II: Possible effect of OCs on mitogen- and antigen-induced lymphocyte proliferation. Journal of Toxicology and Environmental Health - Part A, 68(6), pp. 457-484.

Lie, E., H.J.S. Larsen, S. Larsen, G.M. Johnsen, A.E. Derocher, N.J. Lunn, R.J. Norstrom, O. Wiig, and J.U. Skaare, 2004: Does high organochlorine (OC) exposure impair the resistance to infection in polar bears (Ursus maritimus)? Part I: effect of OCs on the humoral immunity. Journal of Toxicology and Environmental Health - Part A, 67(7), pp. 555-582.

Lindroth, R.L., B.J. Kopper, W.F.J. Parsons, J.G. Bockheim, D.F. Karnosky, G.R. Hendrey, K.S. Pregitzer, J.G. Isebrands, and J. Sober, 2001: Consequences of elevated carbons dioxide and ozone for foliar chemical composition and dynamics in trembling aspen (Populus tremuloides)

and paper birch (Betula papyrifera). Environmental Pollution, 115(3), pp. 395-404.
Lioubimtseva, E., and J.M. Adams, 2004: Possible implications of increased carbon dioxide levels and climate change for desert ecosystems. Environmental Management, 33(Supplement 1), pp. S388-S404.
Lischke, H., A. Guisan, A. Fischlin, J. Williams, and H. Bugmann, 1998: Vegetation responses to climate change in the Alps: modeling studies. In: Views from the Alps: regional perspectives on climate change [Cebon, P., U. Dahinden, H.C. Davies, D.M. Imboden, and C.C. Jager (eds.)]. MIT Press, Boston, Massachusetts a.o., pp. 309-350.
Lischke, H., A.F. Lotter, and A. Fischlin, 2002: Untangling a Holocene pollen record with forest model simulations and independent climate data. Ecological Modelling, 150(1), pp. 1-21.
Llorens, L., and J. Penuelas, 2005: Experimental evidence of future drier and warmer conditions affecting flowering of two co-occurring Mediterranean shrubs. International Journal of Plant Sciences, 166(2), pp. 235-245.
Llorens, L., J. Penuelas, and M. Estiarte, 2003: Ecophysiological responses of two Mediterranean shrubs, Erica multiflora and Globularia alypum, to experimentally drier and warmer conditions. Physiologia Plantarum, 119(2), pp. 231-243.
Llorens, L., J. Penuelas, M. Estiarte, and P. Bruna, 2004: Contrasting growth changes in two dominant species of a Mediterranean shrubland submitted to experimental drought and warming. Annals of Botany, 94(6), pp. 843-853.
Lloret, F., D. Siscart, and C. Dalmases, 2004: Canopy recovery after drought dieback in holm-oak Mediterranean forests of Catalonia (NE Spain). Global Change Biology, 10(12), pp. 2092-2099.
Logan, J.A., J. Regniere, and J.A. Powell, 2003: Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment, 1(3), pp. 130-137.
Lorenzoni, I., N.F. Pidgeon, and R.E. O'Connor, 2005: Dangerous climate change: The role for risk research. Risk Analysis, 25(6), pp. 1387-1398.
Loukos, H., P. Monfray, L. Bopp, and P. Lehodey, 2003: Potential changes in skipjack tuna (Katsuwonus pelamis) habitat from a global warming scenario: modelling approach and preliminary results. Fisheries Oceanography, 12(4-5), pp. 474-482.
Lovejoy, T.E., and L. Hannah (eds.), 2005: Climate change and biodiversity. Yale University Press, New Haven, CT, 418pp.
Lu, C.H., M.K. van Ittersumb, and R. Rabbinge, 2004: A scenario exploration of strategic land use options for the Loess Plateau in northern China. Agricultural Systems, 79(2), pp. 145-170.
Lucht, W., I.C. Prentice, R.B. Myneni, S. Sitch, P. Friedlingstein, W. Cramer, P. Bousquet, W. Buermann, and B. Smith, 2002: Climatic control of the high-latitude vegetation greening trend and Pinatubo effect. Science, 296(5573), pp. 1687-1689.
Luckman, B., 1994: Using multiple high-resolution proxy climate records to reconstruct natural climate variability: an example from the Canadian Rockies. In: Mountain Environments in Changing Climates [Beniston, M. (ed.)]. Routledge Publishing Company, London, England, pp. 42-59.
Ludwig, D., 2000: Limitations of economic valuation of ecosystems. Ecosystems, 3(1), pp. 31-35.
Luo, Y.W.S., D. Hui, and L.L. Wallace, 2001: Acclimatization of soil respiration to warming in a tall grass prairie. Nature (London), 413(11.Oct.), pp. 622-625.
Luterbacher, J., D. Dietrich, E. Xoplaki, M. Grosjean, and H. Wanner, 2004: European seasonal and annual temperature variability, trends, and extremes since 1500. Science, 303(5663), pp. 1499-1503.
MacArthur, R.H., 1972: Geographical ecology patterns in the distribution of species. Harper & Row, New York, 269pp.
Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F. Bazzaz, 2000: Biotic invasions: Causes, epidemiology, global consequences and control. Issues in Ecology, 5, pp. 2-22.
Malcolm, J.R., C.R. Liu, R.P. Neilson, L. Hansen, and L. Hannah, 2006: Global warming and extinctions of endemic species from biodiversity hotspots. Conservation Biology, 20(2), pp. 538-548.

Malcolm, J.R., A. Markham, R.P. Neilson, and M. Garaci, 2002: Estimated migration rates under scenarios of global climate change. Journal of Biogeography, 29(7), pp. 835-849.
Malhi, Y., and O.L. Phillips, 2004: Tropical forests and global atmospheric change: a synthesis. Philosophical Transactions of the Royal Society of London - Series B (Biological Sciences), 359(1443), pp. 549-555.
Malmstrom, C.M., and K.F. Raffa, 2000: Biotic disturbance agents in the boreal forest: considerations for vegetation change models. Global Change Biology, 6(s1), pp. 35-48.
Marra, J., C. Ho, and C.C. Trees, 2003: An algorithm for the calculation of primary productivity from remote sensing data. LDEO Technical Report LDEO-2003-1, Lamont-Doherty Earth Observatory, Palisades, N.Y., 27pp.
Martinez-Vilalta, J., and J. Pinol, 2002: Drought-induced mortality and hydraulic architecture in pine populations of the NE Iberian Peninsula. Forest Ecology and Management, 161(1-3), pp. 247-256.
Martinez-Vilalta, J., J. Pinol, and K. Beven, 2002: A hydraulic model to predict drought-induced mortality in woody plants: an application to climate change in the Mediterranean. Ecological Modelling, 155(2-3), pp. 127-147.
Marubini, F., H. Barnett, C. Langdon, and M.J. Atkinson, 2001: Dependence of calcification on light and carbonate ion concentration for the hermatypic coral Porites compressa. Marine Ecology-Progress Series, 220, pp. 153-162.
Marubini, F., C. Ferrier-Pages, and J.P. Cuif, 2003: Suppression of skeletal growth in scleractinian corals by decreasing ambient carbonate-ion concentration: a cross-family comparison. Proceedings of the Royal Society of London Series B-Biological Sciences, 270(1511), pp. 179-184.
Masek, J.G., 2001: Stability of boreal forest stands during recent climate change: evidence from Landsat satellite imagery. Journal of Biogeography, 28(8), pp. 967-976.
Matarira, C.H., and F.C. Mwamuka, 1996: Vulnerability of Zimbabwe forests to global climate change. Climate Research, 6(2), pp. 135-136.
Matson, P., K.A. Lohse, and S.J. Hall, 2002: The globalization of nitrogen deposition: Consequences for terrestrial ecosystems. Ambio, 31(2), pp. 113-119.
Matthews, D., 2006: Global change: The water cycle freshens up. Nature (London), 439(7078), pp. 793-794.
May, R., 1999a: How the biosphere is organized. Science, 286(5447), pp. 2091-2091.
May, R., 1999b: Unanswered questions in ecology. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 354(1392), pp. 1951-1959.
McCarron, J.K., A.K. Knapp, and J.M. Blair, 2003: Soil C and N responses to woody plant expansion in a mesic grassland. Plant and Soil, 257(1), pp. 183-192.
McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (eds.), 2001: Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel of Climate Change (IPCC). Cambridge University Press, Cambridge a.o., 1032pp.
McClanahan, T.R., N.A. Muthiga, and S. Mangi, 2001: Coral and algal changes after the 1998 coral bleaching: interaction with reef management and herbivores on Kenyan reefs. Coral Reefs, 19(4), pp. 380-391.
McDonald, K.A., and J.H. Brown, 1992: Using montane mammals to model extinctions due to global change. Conservation Biology, 6, pp. 409-415.
McGuire, A.D., J.S. Clein, J.M. Melillo, D.W. Kicklighter, R.A. Meier, C.J. Vorosmarty, and M.C. Serreze, 2000: Modelling carbon responses of tundra ecosystems to historical and projected climate: sensitivity of pan-Arctic carbon storage to temporal and spatial variation in climate. Global Change Biology, 6(Suppl. 1), pp. 141-159.
McKee, D., D. Atkinson, S.E. Collings, J.W. Eaton, A.B. Gill, I. Harvey, K. Hatton, T. Heyes, D. Wilson, and B. Moss, 2003: Response of freshwater microcosm communities to nutrients, fish, and elevated temperature during winter and summer. Limnology and Oceanography, 48(2), pp.

707-722.
McLachlan, J.S., J.S. Clark, and P.S. Manos, 2005: Molecular indicators of tree migration capacity under rapid climate change. Ecology, 86(8), pp. 2088-2098.
McNeely, J.A., 1990: Climate change and biological diversity - policy implications. In: Landscape-Ecological Impact of Climatic Change [Boer, M.M., and R.S. de Groot (eds.)]. IOS Press, Amsterdam, pp. 406-429.
McNeely, J.A., and F. Schutyser (eds.), 2003: Protected areas in 2023: scenarios for an uncertain future. IUCN - The World Conservation Union, Gland, Switzerland, 51pp.
McNeil, B.I., R.J. Matear, and D.J. Barnes, 2004: Coral reef calcification and climate change: The effect of ocean warming. Geophysical Research Letters, 31, pp. L22309, doi:10.1029/2004GL021541.
McWilliams, J.P., I.M. Cote, J.A. Gill, W.J. Sutherland, and A.R. Watkinson, 2005: Accelerating impacts of temperature-induced coral bleaching in the Caribbean. Ecology, 86(8), pp. 2055-2060.
Mearns, L.O., F. Giorgi, P. Whetton, D. Pabon, M. Hulme, and M. Lal, 2003: Guidelines for use of climate scenarios developed from regional climate model experiments. Intergovernmental Panel on Climate Change (IPCC) - Data Distribution Centre (DDC), Norwich, UK, Hamburg, Germany, and New York, USA, 38pp.
Meehl, G.A., and C. Tebaldi, 2004: More intense, more frequent, and longer lasting heat waves in the 21st century. Science, 305(5686), pp. 994-997.
Metzger, M.J., M.D.A. Rounsevell, L. Acosta-Michlik, R. Leemans, and D. Schröter, 2006: The vulnerability of ecosystem services to land use change. Agriculture, Ecosystems and Environment, 114, pp. 69-85.
Midgley, G.F., R.A. Chapman, B. Hewitson, P. Johnston, M. De Wit, G. Ziervogel, P. Mukheibir, L. Van Niekerk, M. Tadross, B.W. Van Wilgen, B. Kgope, P.D. Morant, A. Theron, R.J. Scholes, and G.G. Forsyth, 2005: A status quo, vulnerability and adaptation assessment of the physical and socio-economic effects of climate change in the western Cape. Report to the Western Cape Government, Cape Town, South Africa. CSIR Report No. ENV-S-C 2005-073, CSIR Environmentek, Stellenbosch. South Africa, 170pp.
Midgley, G.F., L. Hannah, D. Millar, M.C. Rutherford, and L.W. Powrie, 2002: Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Global Ecology and Biogeography, 11(6), pp. 445-451.
Midgley, G.F., L. Hannah, D. Millar, W. Thuiller, and A. Booth, 2003: Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. Biological Conservation, 112(1-2), pp. 87-97.
Miles, L.J., 2002: The impact of global climate change on tropical forest biodiversity in Amazonia. PhD thesis, University of Leeds, 328pp.
Milieu en, N., 2005: Natuurbalans 2005. SDU Uitgevers - Wageningen Universiteit en Research Centrum, Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling, Rijksinstituut voor Kust en Zee, Den Haag, The Netherlands, 197pp.
Millar, C.I., R.D. Westfall, D.L. Delany, J.C. King, and L.J. Graumlichc, 2004: Response of subalpine conifers in the Sierra Nevada, California, U.S.A., to 20th-century warming and decadal climate variability. Arctic, Antarctic, and Alpine Research, 36(2), pp. 181-200.
Millennium Ecosystem Assessment, 2005a: Ecosystems and human well-being - volume 5: our human planet: summary for decision-makers. Island Press, Washington, DC, 109pp.
Millennium Ecosystem Assessment, 2005b: Ecosystems and human well-being: synthesis. Island Press, Washington, DC, 155pp.
Millennium Ecosystem Assessment, 2005c: Millennium ecosystem assessment: living beyond our means—natural assets and human well-being (statement from the board). Millenium Ecosystem Assessment - http://www.millenniumassessment.org/, India, France, Kenya, UK, USA, Netherlands, Malaysia, 28pp.
Mitchell, S.W., and F. Csillag, 2001: Assessing the stability and uncertainty of predicted vegetation growth under climatic variability: northern mixed grass prairie. Ecological Modelling, 139(2-3),

pp. 101-121.
Mitra, S., R. Wassmann, and P.L.G. Vlek, 2005: An appraisal of global wetland area and its organic carbon stock. Current Science, 88(1), pp. 25-35.
Moberg, A., D.M. Sonechkin, K. Holmgren, N.M. Datsenko, and W. Karlén, 2005: Highly variable northern hemisphere temperatures reconstructed from low- and high-resolution proxy data. Nature (London), 433(7026), pp. 613-617.
Mock, G. (ed.), 2005: World Resources 2005: The wealth of the poor - managing ecosystems to fight poverty. United Nations Development Programme, United Nations Environment Programme, World Bank, World Resources Institute, Washington, D.C., 266pp.
Moldan, B., S. Percy, J. Riley, T. Hák, J. Rivera, and F.L. Toth, 2005: Choosing responses. In: Ecosystems and human well-being - volume 3: policy responses [Chopra, K., R. Leemans, P. Kumar, and H. Simons (eds.)]. Island Press, Washington DC, pp. 527-548.
Monahan, A.H., J.C. Fyfe, and G.M. Flato, 2000: A regime view of Northern Hemisphere atmospheric variability and change under global warming. Geophysical Research Letters, 27(8), pp. 1139-1142.
Monson, R.K., D.L. Lipson, S.P. Burns, A.A. Turnipseed, A.C. Delany, M.W. Williams, and S.K. Schmidt, 2006: Winter forest soil respiration controlled by climate and microbial community composition. Nature (London), 439(7077), pp. 711-714.
Monson, R.K., A.A. Turnipseed, J.P. Sparks, P.C. Harley, L.E. Scott-Denton, K. Sparks, and T.E. Huxman, 2002: Carbon sequestration in a high-elevation, subalpine forest. Global Change Biology, 8(5), pp. 459-478.
Montenegro, G., R. Ginochio, A. Segura, J.E. Keeley, and M. Gomez, 2004: Fire regimes and vegetation responses in two Mediterranean-climate regions. Revista chilena de historia natural, 77(3), pp. 455-464.
Mooney, H., A. Cropper, and W. Reid, 2005: Confronting the human dilemma - How can ecosystems provide sustainable services to benefit society? Nature (London), 434(31. March), pp. 561-562.
Moorcroft, P.R., G.C. Hurtt, and S.W. Pacala, 2001: A method for scaling vegetation dynamics: The ecosystem demography model (ED). Ecological Monographs, 71(4), pp. 557-585.
Morecroft, M.D., C.E. Bealey, E. Howells, S. Rennie, and I.P. Woiwod, 2002: Effects of drought on contrasting insect and plant species in the UK in the mid-1990s. Global Ecology and Biogeography, 11(1), pp. 7-22.
Morgan, J.A., D.R. Lecain, A.R. Mosier, and D.G. Milchunas, 2001a: Elevated CO2 enhances water relations and productivity and affects gas exchange in C-3 and C-4 grasses of the Colorado shortgrass steppe. Global Change Biology, 7(4), pp. 451-466.
Morgan, J.A., D.E. Pataki, C. Korner, H. Clark, S.J. Del Grosso, J.M. Grunzweig, A.K. Knapp, A.R. Mosier, P.C.D. Newton, P.A. Niklaus, J.B. Nippert, R.S. Nowak, W.J. Parton, H.W. Polley, and M.R. Shaw, 2004: Water relations in grassland and desert ecosystems exposed to elevated atmospheric CO2. Oecologia, 140(1), pp. 11-25.
Morgan, M.G., L.F. Pitelka, and E. Shevliakova, 2001b: Elicitation of expert judgments of climate change impacts on forest ecosystems. Climatic Change, 49(3), pp. 279-307.
Moser, D., S. Dullinger, T. Englisch, H. Niklfeld, C. Plutzar, N. Sauberer, H.G. Zechmeister, and G. Grabherr, 2005: Environmental determinants of vascular plant species richness in the Austrian Alps. Journal of Biogeography, 32(7), pp. 1117-1127.
Moss, B., D. McKee, D. Atkinson, S.E. Collings, J.W. Eaton, A.B. Gill, I. Harvey, K. Hatton, T. Heyes, and D. Wilson, 2003: How important is climate? Effects of warming, nutrient addition and fish on phytoplankton in shallow lake microcosms. Journal of Applied Ecology, 40(5), pp. 782-792.
Mouillot, F., S. Rambal, and R. Joffre, 2002: Simulating climate change impacts on fire frequency and vegetation dynamics in a Mediterranean-type ecosystem. Global Change Biology, 8(5), pp. 423-437.
Mouillot, F., J.P. Ratte, R. Joffre, J.M. Moreno, and S. Rambal, 2003: Some determinants of the spatio-temporal fire cycle in a mediterranean landscape (Corsica, France). Landscape Ecology, 18(7), pp. 665-674.

Musil, C.F., U. Schmiedel, and G.F. Midgley, 2005: Lethal effects of experimental warming approximating a future climate scenario on southern African quartz-field succulents: a pilot study. New Phytologist, 165(2), pp. 539-547.
Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca, and J. Kent, 2000: Biodiversity hotspots for conservation priorities. Nature (London), 403(6772), pp. 853-858.
Najjar, R.G., 2000: The potential impacts of climate change on the mid-Atlantic coastal region (vol 14, pg 219, 2000). Climate Research, 15(2), pp. 160-160.
Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E. Lebre la Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H.H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, and Z. Dadi (eds.), 2000: Emissions scenarios - a special report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, 509pp.
National Research, C., 1999: Perspectives on biodiversity: valuing its role in an everchanging world. National Academies Press, Washington D.C., 168pp.
Neilson, R.P., L.F. Pitelka, A.M. Solomon, R. Nathan, G.F. Midgley, J.M.V. Fragoso, H. Lischke, and K. Thompson, 2005: Forecasting regional to global plant migration in response to climate change. Bioscience, 55(9), pp. 749-759.
Neilson, R.P., I.C. Prentice, B. Smith, T. Kittel, and D. Viner, 1998: Simulated changes in vegetation distribution under global warming. In: Regional impacts of climatic change: An assessment of vulnerability. A special report of the Intergovernmental Panel on Climate Change (IPCC) Working Group II [Watson, R.T., M.C. Zinyowera, R.H. Moss, and D.J. Dokken (eds.)]. Cambridge University Press, Cambridge, UK, pp. 439-456.
Nelson, G.C., 2005: Drivers of ecosystem change: summary chapter. In: Ecosystems and human well-being - volume 1: current state & trends [Hassan, R., R. Scholes, and N. Ash (eds.)]. Island Press, Washington, DC, pp. 73-76.
Nepstad, D.C., A. Verissimo, A. Alencar, C. Nobre, E. Lima, P. Lefebvre, P. Schlesinger, C. Potter, P. Moutinho, E. Mendoza, M. Cochrane, and V. Brooks, 1999: Large-scale impoverishment of Amazonian forests by logging and fire. Nature (London), 398(8.Apr.), pp. 505-508.
Neuvonen, S., 2004: Spatial and temporal variation in biodiversity in the European North. Final Report Work Package 6, SCANNET – Scandinavian/North European Network of Terrestrial Field Bases, 44pp.
Ni, J., 2001: Carbon storage in terrestrial ecosystems of China: Estimates at different spatial resolutions and their responses to climate change. Climatic Change, 49(3), pp. 339-358.
Ni, J., S.P. Harrison, I.C. Prentice, J.E. Kutzbach, and S. Sitch, 2006: Impact of climate variability on present and Holocene vegetation: A model-based study. Ecological Modelling, 191(3-4), pp. 469-486.
Ni, J., M.T. Sykes, I.C. Prentice, and W. Cramer, 2000: Modelling the vegetation of China using the process-based equilibrium terrestrial biosphere model BIOME3. Global Ecology and Biogeography, 9(6), pp. 463-479.
Nicholls, R.J., F.M.J. Hoozemans, and M. Marchand, 1999: Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. Global Environmental Change, 9, pp. S69-S87.
Nicholson, S., 2000: Land surface processes and Sahel climate. Reviews of Geophysics, 38(1), pp. 117-139.
Nicholson, S.E., 2002: What are the key components of climate as a driver of desertification? In: Global desertification. Do humans cause deserts? [Reynolds, J.F., and D.M. Stafford-Smith (eds.)]. Dahlem University Press, Berlin, Germany, pp. 41-57.
Niklaus, P.A., and C.H. Koerner, 2004: Synthesis of a six-year study of calcareous grassland responses to in situ CO2 enrichment. Ecological Monographs, 74(3), pp. 491-511.
Niklaus, P.A., P.W. Leadley, C.H. Koerner, and B. Schmid, 2001: A long-term field study on biodiversity x elevated CO2 interactions in grassland. Ecological Monographs, 71(3), pp. 341-356.

Nippert, J., A. Knapp, and J. Briggs, 2006: Intra-annual rainfall variability and grassland productivity: can the past predict the future? Plant Ecology, pp. 1-10.
Nnadozie, K.C., 1998: Legal and policy approaches at linking the desertification and climate change agenda in Nigeria, pp. 15.
Norby, R.J., P.J. Hanson, E.G. O'Neill, T.J. Tschaplinski, J.F. Weltzin, R.A. Hansen, W.X. Cheng, S.D. Wullschleger, C.A. Gunderson, N.T. Edwards, and D.W. Johnson, 2002: Net primary productivity of a CO2-enriched deciduous forest and the implications for carbon storage. Ecological Applications, 12(5), pp. 1261-1266.
Norby, R.J., J. Ledford, C.D. Reilly, N.E. Miller, and E.G. O'Neill, 2004: Fine-root production dominates response of a deciduous forest to atmospheric CO2 enrichment. Proceedings of the National Academy of sciences of the United States of America, 101(26), pp. 9689-9693.
Norby, R.J., and Y.Q. Luo, 2004: Evaluating ecosystem responses to rising atmospheric CO2 and global warming in a multi-factor world. New Phytologist, 162(2), pp. 281-293.
Nordengren, C., A. Hofgaard, and J.P. Ball, 2003: Availability and quality of herbivore winter browse in relation to tree height and snow depth. Annales Zoologici Fennici, 40(3), pp. 305-314.
Norstrom, R.J., S.E. Belikov, E.W. Born, G.W. Garner, B. Malone, S. Olpinski, M.A. Ramsay, S. Schliebe, I. Stirling, M.S. Stishov, M.K. Taylor, and O. Wiig, 1998: Chlorinated hydrocarbon contaminants in polar bears from eastern Russia, North America, Greenland, and Svalbard: Biomonitoring of Arctic pollution. Archives of Environmental Contamination and Toxicology, 35(2), pp. 354-367.
Notholt, J., Z. Kuang, C.P. Rinsland, G.C. Toon, M. Rex, N. Jones, T. Albrecht, H. Deckelmann, J. Krieg, C. Weinzierl, H. Bingemer, R. Weller, and O. Schrems, 2003: Enhanced upper tropical tropospheric COS: Impact on the stratospheric aerosol layer. Science, 300(5617), pp. 307-310.
Novelli, P.C., K.A. Masarie, P.M. Lang, B.D. Hall, R.C. Myers, and J.W. Elkins, 2003: Reanalysis of tropospheric CO trends: Effects of the 1997–1998 wildfires. Journal of Geophysical Research (Atmosphere), 108 (D15(D15), pp. 4464.
Novick, K.A., P.C. Stoy, G.G. Katul, D.S. Ellsworth, M.B.S. Siqueira, J. Juang, and R. Oren, 2004: Carbon dioxide and water vapor exchange in a warm temperate grassland. Oecologia, 138(2), pp. 259-274.
Nowak, R.S., S.F. Zitzer, D. Babcock, V. Smith-Longozo, T.N. Charlet, J.S. Coleman, J.R. Seemann, and S.D. Smith, 2004: Elevated atmospheric CO2 does not conserver soil water in the Mojave Desert. Ecology, 85(1), pp. 93-99.
Nunes, M.C.S., M.J. Vasconcelos, J.M.C. Pereira, N. Dasgupta, and R.J. Alldredge, 2005: Land cover type and fire in Portugal: do fires burn land cover selectively? Landscape Ecol., 20(6), pp. 661-673.
O'Brien, K.L., and R.M. Leichenko, 2000: Double exposure: assessing the impacts of climate change within the context of economic globalization. Global Environmental Change, 10(3), pp. 221-232.
O'Reilly, C.M., S.R. Alin, P.D. Plisnier, A.S. Cohen, and B.A. McKee, 2003: Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. Nature (London), 424(6950), pp. 766-768.
Ogaya, R., and J. Penuelas, 2003: Comparative seasonal gas exchange and chlorophyll fluorescence of two dominant woody species in a Holm Oak Forest. Flora - Morphologie, Geobotanik, Oekophysiologie, 198(2), pp. 132-141.
Ogaya, R., and J. Penuelas, 2004: Phenological patterns of Quercus ilex, Phillyrea latifolia, and Arbutus unedo growing under a field experimental drought. Ecoscience, 11(3), pp. 263-270.
Ogaya, R., J. Penuelas, J. Martinez-Vilalta, and M. Mangiron, 2003: Effect of drought on diameter increment of Quercus ilex, Phillyrea latifolia, and Arbutus unedo in a holm oak forest of NE Spain. Forest Ecology and Management, 180(1-3), pp. 175-184.
Ogden, J., L. Basher, and M. McGlone, 1998: Fire, forest regeneration and links with early human habitation: Evidence from New Zealand. Annals of Botany, 81(6), pp. 687-696.
Ogutu, J.O., and N. Owen-Smith, 2003: ENSO, rainfall and temperature influences on extreme population declines among African savanna ungulates. Ecology Letters, 6(5), pp. 412-419.

Opdam, P., and D. Wascher, 2004: Climate change meets habitat fragmentation: linking landscape and biogeographical scale level in research and conservation. Biological Conservation, 117(3), pp. 285-297.

Oren, R., D.S. Ellsworth, K.H. Johnsen, N. Phillips, B.E. Ewers, C. Maier, K.V.R. Schafer, H. McCarthy, G. Hendrey, S.G. McNulty, and G.G. Katul, 2001: Soil fertility limits carbon sequestration by forest ecosystems in a CO2-enriched atmosphere. Nature (London), 411(6836), pp. 469-472.

Orr, J.C., V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.K. Plattner, K.B. Rodgers, C.L. Sabine, J.L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.F. Weirig, Y. Yamanaka, and A. Yool, 2005: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature (London), 437(7059), pp. 681-686.

Osmond, B., G. Ananyev, J. Berry, C. Langdon, Z. Kolber, G. Lin, R. Monson, C. Nichol, U. Rascher, U. Schurr, S. Smith, and D. Yakir, 2004: Changing the way we think about global change research: scaling up in experimental ecosystem science. Global Change Biology, 10(4), pp. 393-407.

Ostendorf, B., D.W. Hilbert, and M.S. Hopkins, 2001: The effect of climate change on tropical rainforest vegetation pattern. Ecological Modelling, 145(2-3), pp. 211-224.

Pagiola, S., K. von Ritter, and J.T. Bishop, 2004: Assessing the economic value of ecosystem conservation. Environment Department Paper No. 101, The World Bank Environment Department, Washington, D.C., USA, 66pp.

Parmesan, C., T.L. Root, and M.R. Willig, 2000: Impacts of extreme weather and climate on terrestrial biota. Bulletin of the American Meteorological Society, 81(3), pp. 443-450.

Parry, M.L. (ed.), 2000: Title., Jackson Environmental Institute, University of East Anglia, Norwich, U.K., 320pp.

Pauli, H., M. Gottfried, T. Dirnböck, S. Dullinger, and G. Grabherr, 2003: Assessing the long-term dynamics of endemic plants at summit habitats. In: Alpine biodiversity in Europe [Nagy, L.G., G, C. Körner, and D. Thompson (eds.)]. Springer-Verlag, Berlin Heidelberg, pp. 195-207.

Pauli, H., M. Gottfried, and G. Grabherr, 2001: High summits of the Alps in a changing climate. In: Fingerprints of Climate Change [Walther, G.R. (ed.)]. Kluwer Academic, New York, pp. 139-149.

Pauly, D., V. Christensen, S. Guênette, T.J. Pitcher, U.R. Sumaila, C. Walters, R. Watson, and D. Zeller, 2002: Towards sustainability in world fisheries. Nature (London), 418(8.Aug.), pp. 689-695.

Pausas, J.G., and D. Abdel Malak, 2004: Spatial and temporal patterns of fire and climate change in the eastern Iberian Peninsula (Mediterranean Basin). In: Ecology, Conservation and Management of Mediterranean Climate Ecosystems of the World.10th International Conference on Mediterranean Climate Ecosystems [Arianoutsou, M., and V.P. Papanastasis (eds.)]. Millpress, Rotterdam, Rhodes, Greece.

Pearce, D., 1998: Auditing the Earth - the value of the world's ecosystem services and natural capital. Environment, 40(2), pp. 23-28.

Pearson, R.G., 2006: Climate change and the migration capacity of species. Trends in Ecology and Evolution, 21(3), pp. 111-113.

Pearson, R.G., and T.P. Dawson, 2005: Long-distance plant dispersal and habitat fragmentation: identifying conservation targets for spatial landscape planning under climate change. Biological Conservation, 123(3), pp. 389-401.

Peck, L.S., K.E. Webb, and D.M. Bailey, 2004: Extreme sensitivity of biological function to temperature in Antarctic marine species. Functional Ecology, 18(5), pp. 625-630.

Pederson, G.T., S.T. Gray, D.B. Fagre, and L.J. Graumlich, 2006: Long-duration drought variability and impacts on ecosystem services: a case study from Glacier National Park, Montana. Earth Interactions, 10(4), pp. 1-28.

Peltola, H., S. Kellomaki, and H. Vaisanen, 1999: Model computations of the impact of climatic

change on the windthrow risk of trees. Climatic Change, 41(1), pp. 17-36.
Peng, C., and M.J. Apps, 1999: Modelling the response of net primary productivity (NPP) of boreal forest ecosystems to changes in climate and fire disturbance regimes. Ecological Modelling, 122(3), pp. 175-193.
Peng, C., and M.J. Apps, 2000: Simulating global soil-CO2 flux and its response to climate change. Journal of Environmental Sciences, 12(3), pp. 257-265.
Penuelas, J., and M. Boada, 2003: A global change-induced biome shift in the Montseny mountains (NE Spain). Global Change Biology, 9(2), pp. 131-140.
Penuelas, J., and I. Filella, 2001: Responses to a warming world. Science, 294(5543), pp. 793-795.
Penuelas, J., F. Lloret, and R. Montoya, 2001: Severe drought effects on Mediterranean woody flora in Spain. Forest Science, 47(2), pp. 214-218.
Peters, R.L., and J.D.S. Darling, 1985: The greenhouse effect and nature reserves - global warming would diminish biological diversity by causing extinctions among reserve species. Bioscience, 35(11), pp. 707-717.
Peterson, A.T., 2003: Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences. Global Change Biology, 9(5), pp. 647-655.
Peterson, A.T., M.A. Ortega-Huerta, J. Bartley, V. Sanchez-Cordero, J. Soberon, R.H. Buddemeier, and D.R.B. Stockwell, 2002: Future projections for Mexican faunas under global climate change scenarios. Nature (London), 416(6881), pp. 626-629.
Peterson, C.J., 2000: Catastrophic wind damage to North American forests and the potential impact of climate change. Science of the Total Environment, 262(3), pp. 287-311.
Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.M. Barnola, I. Basile, M. Benders, J. Chappellaz, M. Davis, G. Delaygue, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. Pépin, C. Ritz, E. Saltzman, and M. Stievenard, 1999: Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature (London), 399(3.Jun.), pp. 429-436.
Peylin, P., P. Bousquet, C. Le Quere, S. Sitch, P. Friedlingstein, G. McKinley, N. Gruber, P. Rayner, and P. Ciais, 2005: Multiple constraints on regional CO2 flux variations over land and oceans. Global Biogeochemical Cycles, 19(1)
Phillips, O.L., R.V. Martinez, L. Arroyo, T.R. Baker, T. Killeen, S.L. Lewis, Y. Malhi, A.M. Mendoza, D. Neill, P.N. Vargas, M. Alexiades, C. Ceron, A. Di Fiore, T. Erwin, A. Jardim, W. Palacios, M. Saldias, and B. Vinceti, 2002: Increasing dominance of large lianas in Amazonian forests. Nature (London), 418(6899), pp. 770-774.
Phoenix, G.K., and J.A. Lee, 2004: Predicting impacts of Arctic climate change: Past lessons and future challenges. Ecological Research, 19(1), pp. 65-74.
Pielke Sr, R.A., 2005: Land use and climate change. Science, 310(5754), pp. 1625-1626.
Pierce, J.L., G.A. Meyer, and A.J. Timothy Jull, 2004: Fire-induced erosion and millennial-scale climate change in northern ponderosa pine forests. Nature (London), 432(7013), pp. 87-90.
Podur, J., D.L. Martell, and F. Csillag, 2003: Spatial patterns of lightning-caused forest fires in Ontario, 1976-1998. Ecological Modelling, 164(1), pp. 1-20.
Podur, J., D.L. Martell, and K. Knight, 2002: Statistical quality control analysis of forest fire activity in Canada. Canadian Journal of Forest Research, 32(2), pp. 195-205.
Poff, L.N., M.M. Brinson, and J.W.J. Day, 2002: Aquatic ecosystems and global climate change: potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Pew Center on Global Climate Change, Arlington, VA, USA, 44pp.
Poorter, H., and M. Perez-Soba, 2001: Growth response of plants to elevated CO2 under sub-optimal environmental conditions. Oecologia, 129, pp. 1-20.
Pounds, J.A., 2001: Climate and amphibian declines. Nature (London), 410(6829), pp. 639-640.
Pounds, J.A., M.R. Bustamante, L.A. Coloma, J.A. Consuegra, M.P.L. Fogden, P.N. Foster, E. La Marca, K.L. Masters, A. Merino-Viteri, R. Puschendorf, S.R. Ron, G.A. Sanchez-Azofeifa, C.J. Still, and B.E. Young, 2006: Widespread amphibian extinctions from epidemic disease driven by global warming. Nature (London), 439(7073), pp. 161-167.
Pounds, J.A., M.P.L. Fogden, and J.H. Campbell, 1999: Biological response to climate change on a

tropical mountain. Nature (London), 398(6728), pp. 611-615.
Pounds, J.A., and R. Puschendorf, 2004: Ecology - Clouded futures. Nature (London), 427(6970), pp. 107-109.
Prather, M., and D. Enhalt, 2001: Atmospheric chemistry and greenhouse gases. In: Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel of Climate Change (IPCC) [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge a.o., pp. 239-287.
Prentice, I.C., A. Bondeau, W. Cramer, S.P. Harrison, T. Hickler, W. Lucht, S. Sitch, B. Smith, and M.T. Sykes, 2006: Dynamic global vegetation modelling: quantifying terrestrial ecosystem responses to large-scale environmental change. In: Terrestrial Ecosystems in a Changing World [Canadell, J., D.E. Pataki, and P. L.F (eds.)]. Springer-Verlag, Berlin.
Prentice, I.C., and D. Jolly, 2000: Mid-Holocene and glacial-maximum vegetation geography of the northern continents and Africa. Journal of Biogeography, 27(3), pp. 507-519.
Preston, B.L., 2007: Risk-based reanalysis of the effects of climate change on U.S. cold-water habitat. Climatic Change, pp. 29 (submitted).
Price, D.T., C.H. Peng, M.J. Apps, and D.H. Halliwell, 1999: Simulating effects of climate change on boreal ecosystem carbon pools in central Canada. Journal of Biogeography, 26(6), pp. 1237-1248.
Price, D.T., N.E. Zimmermann, P.J. van der Meer, M.J. Lexer, P. Leadley, I.T.M. Jorritsma, J. Schaber, D.F. Clark, P. Lasch, S. McNulty, J.G. Wu, and B. Smith, 2001: Regeneration in gap models: Priority issues for studying forest responses to climate change. Climatic Change, 51(3-4), pp. 475-508.
Price, J., 2003: Climate change, birds, and ecosystems - Why should we care? In: Managing for Healthy Ecosystems [Rapport, D.J., W.L. Lasley, D.E. Rolston, N.O. Nielsen, C.O. Qualset, and A.B. Damania (eds.)]. Lewis Publishers, Boca Raton, FL, pp. 471-475.
Price, J.T., and P. Glick, 2002: The birdwatcher's guide to global warming. National Wildlife Federation and American Bird Conservancy, Washington, D.C., 36pp.
Price, J.T., and T.L. Root, 2001: Climate change and Neotropical migrants. Transactions Of The North American Wildlife And Natural Resources Conference, 66, pp. 371-379.
Price, J.T., and T.L. Root, 2005: Potential Impacts of climate change on Neotropical migrants: management implications. In: Bird Conservation Implementation and Integration in the Americas [Ralph, C.J., and T.D. Rich (eds.)]. U.S. Forest Service, Arcata, CA, pp. 1123-1128.
Prospero, J.M., and P.J. Lamb, 2003: African droughts and dust transport to the Caribbean: Climate change implications. Science, 302(5647), pp. 1024-1027.
Pyke, C.R., and J. Marty, 2005: Cattle grazing mediates climate change impacts on ephemeral wetlands. Conservation Biology, 19(5), pp. 1619-1625.
Rambal, S., J.M. Ourcival, R. Joffre, F. Mouillot, Y. Nouvellon, M. Reichstein, and A. Rocheteau, 2003: Drought controls over conductance and assimilation of a Mediterranean evergreen ecosystem: scaling from leaf to canopy. Global Change Biology, 9(12), pp. 1813-1824.
Ramsay, M.A., and I. Stirling, 1988: Reproductive biology and ecology of female polar bears (Ursus maritimus). Journal of Zoology, 214, pp. 601-634.
Randerson, J.T., G.R.v.d. Werf, G.J. Collatz, L. Giglio, C.J. Still, P. Kasibhatla, J.B. Miller, J.W.C. White, R.S. Defries, and E.S. Kasischke, 2005: Fire emissions from C 3 and C 4 vegetation and their influence on interannual variability of atmospheric CO 2 and d 13 CO 2. Global Biogeochemical Cycles, 19, pp. GB2019.
Rasmussen, L., C. Beier, and A. Bergstedt, 2002: Experimental manipulations of old pine forest ecosystems to predict the potential tree growth effects of increased CO2 and temperature in a future climate. Forest Ecology and Management, 158(1-3), pp. 179-188.
Raven, J., K. Caldeira, H. Elderfield, O. Hoegh-Guldberg, P. Liss, U. Riebesell, J. Shepherd, C. Turley, and A. Watson, 2005: Ocean acidification due to increasing atmospheric carbon dioxide. Policy document 12/05, The Royal Society The Clyvedon Press Ltd, Cardiff, UK, 68pp.

Ravindranath, N.H., and R. Sukumar, 1998: Climate change and tropical forests in India. Climatic Change, 39(2-3), pp. 563-581.

Rebetez, M., 2004: Summer 2003 maximum and minimum daily temperatures over a 3300 m altitudinal range in the Alps. Climate Research, 27(1), pp. 45-50.

Rebetez, M., and M. Dobbertin, 2004: Climate change may already threaten Scots pine stands in the Swiss Alps. Theoretical and Applied Climatology, 79(1-2), pp. 1-9.

Reich, P.B., S.E. Hobbie, T. Lee, D.S. Ellsworth, J.B. West, D. Tilman, J.M.H. Knops, S. Naeem, and J. Trost, 2006: Nitrogen limitation constrains sustainability of ecosystem response to CO2. 440(7086), pp. 922-925.

Reichstein, M., J.D. Tenhunen, O. Roupsard, J.M. Ourcival, S. Rambal, F. Miglietta, A. Peressotti, M. Pecchiari, G. Tirone, and R. Valentini, 2002: Severe drought effects on ecosystem CO2 and H2O fluxes at three Mediterranean evergreen sites: revision of current hypotheses? Global Change Biology, 8(10), pp. 999-1017.

Reid, W.V., H.A. Mooney, A. Cropper, D. Capistrano, S.R. Carpenter, K. Chopra, P. Dasgupta, T. Dietz, A.K. Duraiappah, R. Hassan, R. Kasperson, R. Leemans, R.M. May, A.J. McMichael, P. Pingali, C. Samper, R. Scholes, R.T. Watson, A.H. Zakri, Z. Shidong, N.J. Ash, E. Bennett, P. Kumar, M.J. Lee, C. Raudsepp-Hearne, H. Simons, J. Thonell, and M.B. Zurek (eds.), 2005: Ecosystems and human well-being: synthesis. Island Press, Washington, DC, 155pp.

Reynaud, S., N. Leclercq, S. Romaine-Lioud, C. Ferrier-Pages, J. Jaubert, and J.P. Gattuso, 2003: Interacting effects of CO2 partial pressure and temperature on photosynthesis and calcification in a scleractinian coral. Global Change Biology, 9(11), pp. 1660-1668.

Richards, M., 2003: Poverty Reduction, Equity and Climate Change: Global Governance Synergies or Contradictions? Globalisation and Poverty Programme. Government Report, Overseas Development Institute (http://www.odi.org.uk/), London, U.K., 14pp.

Riebesell, U., I. Zondervan, B. Rost, P.D. Tortell, R.E. Zeebe, and F.M.M. Morel, 2000: Reduced calcification of marine plankton in response to increased atmospheric CO2. Nature (London), 407(21.Sep.), pp. 364-367.

Riedo, M., D. Gyalistras, and J. Fuhrer, 2000: Net primary production and carbon stocks in differently managed grasslands: Simulation of site-specific sensitivity to an increase in atmospheric CO2 and to climate change. Ecological Modelling, 134, pp. 207-227.

Rietkerk, M., S.C. Dekker, P.C. de Ruiter, and J. van de Koppel, 2004: Self-organized patchiness and catastrophic shifts in ecosystems. Science, 305(5692), pp. 1926-1929.

Rillig, M.C., S.F. Wright, M.R. Shaw, and C.B. Field, 2002: Artificial climate warming positively affects arbuscular mycorrhizae but decreases soil aggregate water stability in an annual grassland. OIKOS, 97(1), pp. 52-58.

Ritchie, J.C., and G.M. MacDonald, 1986: The patterns of post-glacial spread of white spruce. Journal of Biogeography, 13(6), pp. 527-540.

Roberts, C.M., C.J. McClean, J.E.N. Veron, J.P. Hawkins, G.R. Allen, D.E. McAllister, C.G. Mittermeier, F.W. Schueler, M. Spalding, F. Wells, C. Vynne, and T.B. Werner, 2002: Marine biodiversity hotspots and conservation priorities for tropical reefs. Science, 295(5558), pp. 1280-1284.

Robinson, R.A., J.A. Learmonth, A.M. Hutson, C.D. Macleod, T.H. Sparks, D.I. Leech, G.J. Pierce, M.M. Rehfisch, and H.Q.P. Crick, 2005: Climate change and migratory species. BTO Research Report, Department for Environment, Food and Rural Affairs (Defra), London, 414pp.

Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig, and J.A. Pounds, 2003: Fingerprints of global warming on wild animals and plants. Nature (London), 421(6918), pp. 57-60.

Root, T.L., and S.H. Schneider, 1995: Ecology and climate: research strategies and implications. Science, 269(5222), pp. 334-341.

Ross, D.J., K.R. Tate, P.C.D. Newton, and H. Clark, 2002: Decomposability of C3 and C4 grass litter sampled under different concentrations of atmospheric carbon dioxide at a natural CO2 spring. Plant and Soil, 240(2), pp. 275-286.

Rouault, M., J.L. Melice, C.J.C. Reason, and J.R.E. Lutijeharms, 2005: Climate variability at Marion

Island, Southern Ocean, since 1960. Journal of Geophysical Research (Oceans), 110(C5)
Rounsevell, M.D.A., P.M. Berry, and P.A. Harrison, 2006: Future environmental change impacts on rural land use and biodiversity: a synthesis of the ACCELERATES project. Environmental Science and Policy, 9, pp. 93-100.
Rounsevell, M.D.A., F. Ewert, I. Reginster, R. Leemans, and T.R. Carter, 2005: Future scenarios of European agricultural land use II. Projecting changes in cropland and grassland. Agriculture, Ecosystems and Environment, 107(2-3), pp. 117-135.
Rupp, T.S., A.M. Starfield, and F.S. Chapin, 2000: A frame-based spatially explicit model of subarctic vegetation response to climatic change: comparison with a point model. Landscape Ecology, 15(4), pp. 383-400.
Rustad, L.E., J.L. Campbell, G.M. Marion, R.J. Norby, M.J. Mitchell, A.E. Hartley, J.H.C. Cornelissen, and J. Gurevitch, 2001: A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia, 126(4), pp. 543-562.
Rutherford, M.C., G.F. Midgley, W.J. Bond, L.W. Powrie, R. Roberts, and J. Allsopp (eds.), 2000: Plant biodiversity: Vulnerability and adaptation assessment. Department of Environmental Affairs and Tourism, Pretoria, South Africa, 59pp.
Sabine, C.L., M. Heimann, P. Artaxo, D.C.E. Bakker, C.T.A. Chen, C.B. Field, and N. Gruber, 2004: Current status and past trends of the global carbon cycle. In: Global Carbon Cycle: Integrating Humans, Climate, and the Natural World [Field, C.B., and M.R. Raupach (eds.)]. Island Press, Washington, D.C., pp. 17-44.
SADC, 1996: Policy and strategy for environment an sustainable development: Towards equity-led growth and sustainable development in Southern Africa. Southern Africa Development Community - Environment and Land Management Sector (SADC-ELMS), Maseru, Lesotho, 55pp.
Sage, R.F., and D.S. Kubien, 2003: Quo vadis C-4? An ecophysiological perspective on global change and the future of C4 plants. Photosynthesis Research, 77(2-3), pp. 209-225.
Sala, O.E., 2005: Biodiversity across scenarios. In: Ecosystems and human well-being - volume 2: scenarios [Carpenter, S., P. Pingali, E. Bennett, and M. Zurek (eds.)]. Island Press, Washington, DC, pp. 375-408.
Sala, O.E., I.F.S. Chapin, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.H. Lodge, H.A. Mooney, M. Oesterheld, N. Leroy Poff, M.T. Sykes, B.H. Walker, M. Walker, and D.H. Wall, 2000: Global biodiversity scenarios for the year 2100. Science, 287(5459), pp. 1770-1774.
Salvador, R., F. Lloret, X. Pons, and J. Pinol, 2005: Does fire occurrence modify the probability of being burned again? A null hypothesis test from Mediterranean ecosystems in NE Spain. Ecological Modelling, 188(2-4), pp. 461-469.
Sanchez, E., C. Gallardo, M.A. Gaertner, A. Arribas, and M. Castro, 2004: Future climate extreme events in the Mediterranean simulated by a regional climate model: a first approach. Global and Planetary Change, 44(1-4), pp. 163-180.
Santelmann, M.V., D. White, K. Freemark, J.I. Nassauer, J.M. Eilers, K.B. Vache, B.J. Danielson, R.C. Corry, M.E. Clark, S. Polasky, R.M. Cruse, J. Sifneos, H. Rustigian, C. Coiner, J. Wu, and D. Debinski, 2004: Assessing alternative futures for agriculture in Iowa, USA. Landscape Ecology, 19(4), pp. 357-374.
Sanz-Elorza, M., E.D. Dana, A. Gonzalez, and E. Sobrino, 2003: Changes in the high-mountain vegetation of the central Iberian peninsula as a probable sign of global warming. Ann Bot, 92(2), pp. 273-280.
Sardans, J., and J. Penuelas, 2004: Increasing drought decreases phosphorus availability in an evergreen Mediterranean forest. Plant & Soil, 267(1 - 2), pp. 367-377.
Sarmiento, J., 2000: That sinking feeling. Nature (London), 408(9.Nov.), pp. 155-156.
Sarmiento, J.L., N. Gruber, M. Brzezinksi, and J. Dunne, 2004a: High latitude controls of thermocline nutrients and low latitude biological productivity. Nature (London), 426, pp. 56-60.
Sarmiento, J.L., T.M.C. Hughes, R.J. Stouffer, and S. Manabe, 1998: Simulated response of the ocean

carbon cycle to anthropogenic climate warming. Nature (London), 393(21 May), pp. 245-249.
Sarmiento, J.L., R. Slater, R. Barber, L. Bopp, S.C. Doney, A.C. Hirst, J. Kleypas, R. Matear, U. Mikolajewicz, P. Monfray, V. Soldatov, S.A. Spall, and R. Stouffer, 2004b: Response of ocean ecosystems to climate warming. Global Biogeochemical Cycles, 18(3), pp. GB3003 1-23.
Schafer, K.V.R., R. Oren, D.S. Ellsworth, C.T. Lai, J.D. Herrick, A.C. Finzi, D.D. Richter, and G.G. Katul, 2003: Exposure to an enriched CO2 atmosphere alters carbon assimilation and allocation in a pine forest ecosystem. Global Change Biology, 9(10), pp. 1378-1400.
Schallenberg, M., C.J. Hall, and C.W. Burns, 2001: Climate change alters zooplankton community structure and biodiversity in coastal wetlands.
Schaphoff, S., W. Lucht, D. Gerten, S. Sitch, W. Cramer, and I.C. Prentice, 2006: Terrestrial biosphere carbon storage under alternative climate projections. Climatic Change
Schär, C., P.L. Vidale, D. Lüthi, C. Frei, C. Häberli, M.A. Liniger, and C. Appenzeller, 2004: The role of increasing temperature variability in European summer heatwaves. Nature (London), 427(6972 (22.Jan.)), pp. 332-336.
Scharlemann, J.P.W., R.E. Green, and A. Balmford, 2004: Land-use trends in Endemic Bird Areas: global expansion of agriculture in areas of high conservation value. Global Change Biology, 10(12), pp. 2046-2051.
Scheffer, M., S. Carpenter, J.A. Foley, C. Folke, and B. Walker, 2001: Catastropohic shifts in ecosystems. Nature (London), 413(11.Oct.), pp. 591-596.
Scheller, R.M., and D.J. Mladenoff, 2005: A spatially interactive simulation of climate change, harvesting, wind, and tree species migration and projected changes to forest composition and biomass in northern Wisconsin, USA. Global Change Biology, 11(2), pp. 307-321.
Schellnhuber, H.J., 2002: Coping with Earth system complexity and irregularity. In: Challenges of a changing Earth [Steffen, W., D. Jäger, and C. Bradshaw (eds.)]. Springer, Berlin, pp. 151-156.
Schimper, A.F.W., 1903: Plant geography on a physiological basis. Clarendon Press, Oxford.
Schneider, S.H., 2004: Abrupt non-linear climate change, irreversibility and surprise. Global Environmental Change, 14(3), pp. 245-258.
Schoennagel, T., T.T. Veblen, and W.H. Romme, 2004: The interaction of fire, fuels, and climate across rocky mountain forests. Bioscience, 54(7), pp. 661-676.
Scholes, R.J., and S.R. Archer, 1997: Tree-grass interactions in savannas. Annual Review of Ecology and Systematics, 28, pp. 517-544.
Scholes, R.J., G. von Maltitz, M. de Wit, G.O. Hughes, G. Midgley, and B. Erasmus, 2004: Helping biodiversity adapt to climate change. LUMONET - Science Development Network, Finnish Environment Institute, Helsinki, Finland, 2pp.
Scholze, M., W. Knorr, N.W. Arnell, and I.C. Prentice, 2007: A climate change risk analysis for world ecosystems. Proceedings of the National Academy of sciences of the United States of America, pp. 19(submitted).
Schroder, A., L. Persson, and A.M. De Roos, 2005: Direct experimental evidence for alternative stable states: a review. OIKOS, 110(1), pp. 3-19.
Schroter, D., W. Cramer, R. Leemans, I.C. Prentice, M.B. Araujo, N.W. Arnell, A. Bondeau, H. Bugmann, T.R. Carter, C.A. Gracia, A.C. Dela vega-Leinert, M. Erhard, F. Ewert, M. Glendining, J.I. House, S. Kankaanpaa, R.J.T. Klein, S. Lavorel, M. Lindner, M.J. Metzger, J. Meyer, T.D. Mitchell, I. Reginster, M. Rounsevell, S. Sabate, S. Sitch, B. Smith, J. Smith, P. Smith, M.T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, S. Zaehle, and B. Zierl, 2005: Ecosystem service supply and vulnerability to global change in Europe. Science, 310(5752), pp. 1333-1337.
Schulze, E.D., and A. Freibauer, 2005: Carbon unlocked from soils. Nature (London), 437(7056), pp. 205-206.
Schumacher, S., H. Bugmann, and D.J. Mladenoff, 2004: Improving the formulation of tree growth and succession in a spatially explicit landscape model. Ecological Modelling, 180(1), pp. 175-194.
Schwinning, S., and O.E. Sala, 2004: Hierarchy of responses to resource pulses in and and semi-arid ecosystems. Oecologia, 141(2), pp. 211-220.
Semazzi, F.H.M., and Y. Song, 2001: A GCM study of climate change induced by deforestation in

Africa. Climate Research, 17(2), pp. 169-182.
Serreze, M.C., F. Carse, R.G. Barry, and J.C. Rogers, 1997: Icelandic low cyclone activity: climatological features, linkages with the NAO, and relationships with recent changes in the Northern Hemisphere Circulation. Journal of Applied Systems Analysis, 10(3), pp. 453-464.
Shafer, S.L., P.J. Bartlein, and R.S. Thompson, 2001: Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems, 4(3), pp. 200-215.
Shaw, M.R., E.S. Zavaleta, N.R. Chiariello, E.E. Cleland, H.A. Mooney, and C.B. Field, 2002: Grassland responses to global environmental changes suppressed by elevated CO2. Science, 298(5600), pp. 1987.
Sheppard, C.R.C., 2003: Predicted recurrences of mass coral mortality in the Indian Ocean. Nature (London), 425(6955), pp. 294-297.
Shiyatov, S.G., 2003: Rates of change in the upper treeline ecotone in the Polar Ural Mountains. PAGES Newsletter, 11(1), pp. 8-10.
Shvidenko, A., C.V. Barber, and R. Persson, 2005: Forest and woodland systems. In: Ecosystems and human well-being - volume 1: current state & trends [Hassan, R., R. Scholes, and N. Ash (eds.)]. Island Press, Washington, DC, pp. 585-621.
Siddiqui, K.M., I. Mohammad, and M. Ayaz, 1999: Forest ecosystem climate change impact assessment and adaptation strategies for Pakistan. Climate Research, 12(2-3), pp. 195-203.
Simmons, R.E., P. Barnard, W.R.J. Dean, G.F. Midgley, W. Thuiller, and G. Hughes, 2004: Climate change and birds: perspectives and prospects from southern Africa. Ostrich, 75(4), pp. 295-308.
Singh, H.S., 2003: Vulnerability and adaptability of tidal forests in response to climate change in India. Indian Forester, 129(6), pp. 749-756.
Sitch, S., V. Brovkin, W. von Bloh, D. van Vuuren, B. Assessment, and A. Ganopolski, 2005: Impacts of future land cover changes on atmospheric CO2 and climate. Global Biogeochemical Cycles, 19(2), pp. GB2013.
Sitch, S., A.D. McGuire, J. Kimball, N. Gedney, J. Gamon, R. Emgstrom, A. Wolf, Q. Zhuang, and J. Clein, 2007: Assessing the circumpolar carbon balance of arctic tundra with remote sensing and process-based modelling approaches. Ecological Applications, pp. in press.
Sitch, S., B. Smith, I.C. Prentice, A. Arneth, A. Bondeau, W. Cramer, J.O. Kaplan, S. Levis, W. Lucht, M.T. Sykes, K. Thonicke, and S. Venevsky, 2003: Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Global Change Biology, 9(2), pp. 161-185.
Skaare, J.U., A. Bernhoft, O. Wiig, K.R. Norum, E. Haug, D.M. Eide, and A.E. Derocher, 2001: Relationships between plasma levels of organochlorines, retinol and thyroid hormones from polar bears (Ursus maritimus) at Svalbard. Journal of Toxicology and Environmental Health - Part A, 62(4), pp. 227-241.
Skinner, W.R., M.D. Flannigan, B.J. Stocks, D.L. Martell, B.M. Wotton, J.B. Todd, J.A. Mason, K.A. Logan, and E.M. Bosch, 2002: A 500 hPa synoptic wildland fire climatology for large Canadian forest fires, 1959-1996. Theoretical and Applied Climatology, 71(3 - 4), pp. 157-169.
Skre, O., R. Baxter, R.M.M. Crawford, T.V. Callaghan, and A. Fedorkov, 2002: How will the tundra-taiga interface respond to climate change? Ambio, Special Issue(12), pp. 37-46.
Slaymaker, O., 2001: Why so much concern about climate change and so little attention to land use change? The Canadian Geographer, 45(1), pp. 71-78.
Smith, B., I.C. Prentice, and M.T. Sykes, 2001: Representation of vegetation dynamics in the modelling of terrestrial ecosystems: comparing two contrasting approaches within European climate space. Global Ecology and Biogeography, 10(6), pp. 621-637.
Smith, D.L., and L. Johnson, 2004: Vegetation-mediated changes in microclimate reduce soil respiration as woodlands expand into grasslands. Ecology, 85(12), pp. 3348-3361.
Smith, J.B., and J.K. Lazo, 2001: A summary of climate change impact assessments from the US Country studies program. Climatic Change, 50(1-2), pp. 1-29.
Smith, L.C., G.M. MacDonald, A.A. Velichko, D.W. Beilman, O.K. Borisova, K.E. Frey, K.V. Kremenetski, and Y. Sheng, 2004: Siberian peatlands a net carbon sink and global methane source

since the early Holocene. Science, 303(5656), pp. 353-356.
Smith, L.C., Y. Sheng, G.M. MacDonald, and L.D. Hinzman, 2005: Disappearing arctic lakes. Science, 308(5727 3 June), pp. 1429.
Smith, M.D., and A.K. Knapp, 1999: Exotic plant species in a C-4-dominated grassland: invasibility, disturbance, and community structure. Oecologia, 120(4), pp. 605-612.
Smith, R.D., and E. Malthby, 2003: Using the ecosystem approach to implement the Convention on Biological Diversity: key issues and case studies. Island Press, Chicago, USA, 118pp.
Smith, S.D., T.E. Huxman, S.F. Zitzer, T.N. Charlet, D.C. Housman, J.S. Coleman, L.K. Fenstermaker, J.R. Seemann, and R.S. Nowak, 2000: Elevated CO2 increases productivity and invasive species success in an arid ecosystem. Nature (London), 408(6808), pp. 79-82.
Smith, V.R., 2002: Climate change in the sub-Antarctic: An illustration from Marion Island. Climatic Change, 52(3), pp. 345-357.
Snyder, P.K., C. Delire, and J.A. Foley, 2004: Evaluating the influence of different vegetation biomes on the global climate. Climate Dynamics, 23(3-4), pp. 279-302.
Solomon, A.M., and A.P. Kirilenko, 1997: Climate change and terrestrial biomass: what if trees do not migrate? Global Ecology and Biogeography Letters, 6, pp. 139-148.
Solomon, A.M., and R. Leemans, 1997: Boreal forest carbon stocks and wood supply: past, present and future responses to changing climate, agriculture and species availability. Agricultural and Forest Meteorology, 84, pp. 137-151.
Solorzano, S., M.A. Castillo-Santiago, D.A. Navarrete-Gutierrez, and K. Oyama, 2003: Impacts of the loss of neotropical highland forests on the species distribution: a case study using resplendent quetzal an endangered bird species. Biological Conservation, 114(3), pp. 341-349.
Sorenson, L.G., R. Goldberg, T.L. Root, and M.G. Anderson, 1998: Potential effects of global warming on waterfowl populations breeding in the Northern Great Plains. Climatic Change, 40(2), pp. 343-369.
Soulé, M.E., and M.A. Sanjayan, 1998: Conservation targets: do they help? Science, 279, pp. 2060.
Spehn, E., and C. Körner, 2005: A global assessment of mountain biodiversity and its function. In: Global change and mountain regions: an overview of current knowledge [Huber, U.M., H.K.M. Bugmann, and M.A. Reasoner (eds.)]. Springer, Berlin, pp. 393-400.
Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo, and J.D. Schumacher, 2001: On the temporal variability of the physical environment over the south-eastern Bering Sea. Fisheries Oceanography, 10(1), pp. 81-98.
Stampfli, A., and M. Zeiter, 2004: Plant regeneration directs changes in grassland composition after extreme drought: a 13-year study in southern Switzerland. Journal of Ecology, 92(4), pp. 568-576.
Stapp, P., G.A. Polls, and F.S. Pirero, 1999: Stable isotopes reveal strong marine and El Nino effects on island food webs. Nature (London), 401(30.Sep.), pp. 467-469.
Stefanescu, C., S. Herrando, and F. Paramo, 2004: Butterfly species richness in the north-west Mediterranean Basin: the role of natural and human-induced factors. Journal of Biogeography, 31(6), pp. 905-915.
Stenseth, N.C., and J.W. Hurrell, 2005: Global climate change: building links between the climate and ecosystem impact research communities. Climate Research, 29(3), pp. 181-182.
Still, C.J., P.N. Foster, and S.H. Schneider, 1999: Simulating the effects of climate change on tropical montane cloud forests. Nature (London), 398(6728), pp. 608-610.
Stirling, I., and A.E. Derocher, 1993: Possible impacts of climatic warming on polar bears. Arctic, 46(3), pp. 240-245.
Stirling, I., N.J. Lunn, and J. Iacozza, 1999: Long-term trends in the population ecology of polar bears in western Hudson Bay in relation to climatic change. Arctic, 52(3), pp. 294-306.
Stock, W.D., F. Ludwig, C. Morrow, G.F. Midgley, S.J.E. Wand, N. Allsopp, and T.L. Bell, 2005: Long-term effects of elevated atmospheric CO2 on species composition and productivity of a southern African C-4 dominated grassland in the vicinity of a CO2 exhalation. Plant Ecology, 178(2), pp. 211-224.
Stocks, B.J., M.A. Fosberg, T.J. Lynham, L. Mearns, B.M. Wotton, Q. Yang, J.Z. Jin, K. Lawrence,

G.R. Hartley, J.A. Mason, and D.W. McKenney, 1998: Climate change and forest fire potential in Russian and Canadian boreal forests. Climatic Change, 38(1), pp. 1-13.
Stocks, B.J., J.A. Mason, J.B. Todd, E.M. Bosch, B.M. Wotton, B.D. Amiro, M.D. Flannigan, K.G. Hirsch, K.A. Logan, D.L. Martell, and W.R. Skinner, 2002: Large forest fires in Canada, 1959-1997. Journal of Geophysical Research (Atmosphere), 108(D1), pp. 8149.
Stokstad, E., 2001: U.N. report suggests slowed forest losses. Science, 291(5512), pp. 2294.
Stott, P.A., D.A. Stone, and M.R. Allen, 2004: Human contribution to the European heatwave of 2003. Nature (London), 432(7017), pp. 610-614.
Strengers, B., R. Leemans, B.J. Eickhout, B. de Vries, and A.F. Bouwman, 2004: The land-use projections and resulting emissions in the IPCC SRES scenarios as simulated by the IMAGE 2.2 model. GeoJournal, 61, pp. 381-393.
Sturm, M., C. Racine, and K. Tape, 2001: Climate change - Increasing shrub abundance in the Arctic. Nature (London), 411(6837), pp. 546-547.
Sumner, G.N., R. Romero, V. Homar, C. Ramis, S. Alonso, and E. Zorita, 2003: An estimate of the effects of climate change on the rainfall of Mediterranean Spain by the late twenty first century. Climate Dynamics, 20(7-8), pp. 789-805.
Suyker, A.E., and S.B. Verma, 2001: Year-round observations of the net ecosystem exchange of carbon dioxide in a native tallgrass prairie. Global Change Biology, 7(3), pp. 279-289.
Suyker, A.E., S.B. Verma, and G.G. Burba, 2003: Interannual variability in net CO2 exchange of a native tallgrass prairie. Global Change Biology, 9(2), pp. 255-265.
Symon, C., L. Arris, and B. Heal (eds.), 2005: Arctic climate impact assessment (ACIA) - Scientific report. Cambridge Univ. Press, Cambridge, UK, 1042pp.
Szmant, A.M., 2001: Why are coral reefs world-wide becoming overgrown by algae? 'Algae, algae everywhere, and nowhere a bite to eat!' Coral Reefs, 19(4), pp. 299-302.
Taylor, C.M., E.F. Lambin, N. Stephenne, R.J. Harding, and R.L.H. Essery, 2002: The influence of land use change on climate in the Sahel. Journal of Climate, 15(24), pp. 3615-3629.
Theurillat, J.P., F. Felber, P. Geissler, J.M. Gobat, M. Fierz, A. Fischlin, P. Küpfer, A. Schlüssel, C. Velluti, G.F. Zhao, and J. Williams, 1998: Sensitivity of plant and soil ecosystems of the Alps to climate change. In: Views from the Alps: regional perspectives on climate change [Cebon, P., U. Dahinden, H.C. Davies, D.M. Imboden, and C.C. Jager (eds.)]. MIT Press, Boston, Massachusetts a.o., pp. 225-308.
Theurillat, J.P., and A. Guisan, 2001: Potential impact of climate change on vegetation in the European Alps: a review. Climatic Change, 50, pp. 77-109.
Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams, 2004a: Extinction risk from climate change. Nature (London), 427(6970), pp. 145-148.
Thomas, C.D.W.S.E., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N.F.d.S.M. Erasmus, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, and O.L. Philipps, 2004b: Biodiversity conservation: Uncertainty in predictions of extinction risk/Effects of changes in climate and land use/Climate change and extinction risk (reply). Nature (London), 430(6995), pp. 34.
Thomas, D.S.G., M. Knight, and G.F.S. Wiggs, 2005: Remobilization of southern African desert dune systems by twenty-first century global warming. Nature (London), 435(7046), pp. 1218-1221.
Thomas, D.S.G., and H.C. Leason, 2005: Dunefield activity response to climate variability in the southwest Kalahari. Geomorphology, 64(1-2), pp. 117-132.
Thompson, I.D., M.D. Flannigan, B.M. Wotton, and R. Suffling, 1998: The effects of climate change on landscape diversity: An example in Ontario forests. Environmental Monitoring and Assessment, 49(2-3), pp. 213-233.
Thonicke, K., S. Venevsky, S. Sitch, and W. Cramer, 2001: The role of fire disturbance for global vegetation dynamics: coupling fire into a Dynamic Global Vegetation Model. Global Ecology and Biogeography, 10(6), pp. 661-677.

Thuiller, W., O. Broenniman, G. Hughes, J.R.M. Alkemades, G.F. Midgley, and F. Corsi, 2006: Vulnerability of African mammals to anthropogenic climate change under conservative land transformation assumptions. Global Change Biology, 12, pp. 1-17.
Thuiller, W., S. Lavorel, M.B. Araujo, M.T. Sykes, and I.C. Prentice, 2005: Climate change threats to plant diversity in Europe. Proceedings of the National Academy of sciences of the United States of America, 102(23), pp. 8245-8250.
Thuiller, W., G.F. Midgley, G.O. Hughes, B. Bomhard, G. Drew, M.C. Rutherford, and F.I. Woodward, 2007: Endemic species and ecosystem sensitivity to climate change in Namibia. Global Change Biology, 12, pp. 18(in press).
Thurig, E., E. Kaufmann, R. Frisullo, and H. Bugmann, 2005a: Evaluation of the growth function of an empirical forest scenario model. Forest Ecology and Management, 204(1), pp. 51-66.
Thurig, E., T. Palosuo, J. Bucher, and E. Kaufmann, 2005b: The impact of windthrow on carbon sequestration in Switzerland: a model-based assessment. Forest Ecology and Management, 210(1-3), pp. 337-350.
Timoney, K.P., 2003: The changing disturbance regime of the boreal forest of the Canadian Prairie Provinces. The Forestry Chronicle, 79(3), pp. 502-516.
Tol, R.S.J., 2001: Equitable cost-benefit analysis of climate change policies. Ecological Economics, 36(1), pp. 71-85.
Tole, L., 1998: Source of defeorestation in tropical developing countries. Environmental Management, 22(1), pp. 19-33.
Toman, M., 1998a: Research frontiers in the economics of climate change. Environmental & Resource Economics, 11(3-4), pp. 603-621.
Toman, M., 1998b: Why not to calculate the value of the world's ecosystem services and natural capital. Ecological Economics, 25(1), pp. 57-60.
Tompkins, E.L., and W.N. Adger, 2003: Building resilience to climate change through adaptive management of natural resources. Working Paper 27, Tyndall Centre for Climate Change Research, Norwich, UK, 19pp.
Trenberth, K.E., 1999: Conceptual framework for changes of extremes of the hydrological cycle with climate change. Climatic Change, 42(1), pp. 327-339.
Trigo, R.M., M.G. Pereira, J.M.C. Pereira, B. Mota, T.J. Calado, C.C. da Camara, and F.E. Santo, 2005: The exceptional fire season of summer 2003 in Portugal. Geophysical Research Abstracts, 7, pp. 09690.
Tuchman, N.C., K.A. Wahtera, R.G. Wetzel, N.M. Russo, G.M. Kilbane, L.M. Sasso, and J.A. Teeri, 2003a: Nutritional quality of leaf detritus altered by elevated atmospheric CO2: effects on development of mosquito larvae. Freshwater Biology, 48(8), pp. 1432-1439.
Tuchman, N.C., K.A. Wahtera, R.G. Wetzel, and J.A. Teeri, 2003b: Elevated atmospheric CO2 alters leaf litter quality for stream ecosystems: an in situ leaf decomposition study. Hydrobiologia, 495(1-3), pp. 203-211.
Tuchman, N.C., R.G. Wetzel, S.T. Rier, K.A. Wahtera, and J.A. Teeri, 2002: Elevated atmospheric CO2 lowers leaf litter nutritional quality for stream ecosystem food webs. Global Change Biology, 8(2), pp. 163-170.
Turley, C., J. Blackford, S. Widdicombe, D. Lowe, and P. Nightingale, 2006: Reviewing the impact of increased atmospheric CO2 on oceanic pH and the marine ecosystem. In: Avoiding dangerous climate change [Schellnhuber, H.J.p.C.W., N. Nakicenovic, T. Wigley, and G. Yohe (eds.)]. Cambridge University Press, Cambridge, UK, pp. 65-70.
Turner, M.D., 1999: Spatial and temporal scaling of grazing impact on the species composition and productivity of Sahelian annual grasslands. Journal of Arid Environments, 41(3), pp. 277-297.
Tyrrell, T., P.M. Holligan, and C.D. Mobley, 1999: Optical impacts of oceanic coccolithophore blooms. Journal of Geophysical Research (Planets), 104(C2), pp. 3223-3241.
Udra, I.F., 1988: Plant migrations and problems of paleobotany. Naukova Dumka, Kiev, Russia, 163pp.
UNEP, 2002: Global Environmental Outlook 3: past, present and future perspectives. A report from the GEO Project, United Nations Environment Programme, Nairobi, Kenya, 416pp.

Usher, M.B., T.V. Callaghan, G. Gilchrist, B. Heal, G.P. Juday, H. Loeng, M.A.K. Muir, and P. Prestrud, 2005: Principles of conserving the Arctic's biodiversity. In: Arctic climate impact assessment (ACIA) - scientific report [Symon, C., L. Arris, and B. Heal (eds.)]. Cambridge Univ. Press, Cambridge, UK, pp. 539-596.
Van Auken, O.W., 2000: Shrub invasions of North American semiarid grasslands. Annual Review of Ecology and Systematics, 31(1), pp. 197-215.
Van Dam, R., H. Gitay, M. Finlayson, N.J. Davidson, and B. Orlando, 2002: Climate change and wetlands: impacts, adaptation and mitigation. Ramsar Bureau, Gland, Swirzerland.
van den Bergh, J.C.J.M., 2004: Optimal climate policy is a utopia: from quantitative to qualitative cost-benefit analysis. Ecological Economics, 48(4), pp. 385-393.
van den Born, G.J., R. Leemans, and M. Schaeffer, 2004: Climate change scenarios for dryland west africa 1990-2050. In: The impact of climate change on drylands [Dietz, A.J., R. Ruben, and A. Verhagen (eds.)]. Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 43-48.
Van Kessel, C., J. Nitschelm, W.R. Horwath, D. Harris, F. Walley, A. Luscher, and U. Hartwig, 2000: Carbon-13 input and turn-over in a pasture soil exposed to long-term elevated atmospheric CO2. Global Change Biology, 6(1), pp. 123-135.
van Vliet, A., and R. Leemans, 2006: Rapid species responses to changes in climate requires stringent climate protection target. In: Avoiding dangerous climate change [Schellnhuber, H.J.p.C.W., N. Nakicenovic, T. Wigley, and G. Yohe (eds.)]. Cambridge University Press, Cambridge, UK, pp. 135-141.
van Wijk, M.T., K.E. Clemmensen, G.R. Shaver, M. Williams, T.V. Callaghan, F.S. Chapin, J.H.C. Cornelissen, L. Gough, S.E. Hobbie, S. Jonasson, J.A. Lee, A. Michelsen, M.C. Press, S.J. Richardson, and H. Rueth, 2004: Long-term ecosystem level experiments at Toolik Lake, Alaska, and at Abisko, Northern Sweden: generalizations and differences in ecosystem and plant type responses to global change. Global Change Biology, 10(1), pp. 105-123.
Van Wilgen, B.W., N. Govender, H.C. Biggs, D. Ntsala, and X.N. Funda, 2004: Response of Savanna fire regimes to changing fire-management policies in a large African National Park. Conservation Biology, 18(6), pp. 1533-1540.
Vazquez, A., and J.M. Moreno, 2001: Spatial distribution of forest fires in Sierra de Gredos (Central Spain). Forest Ecology and Management, 147(1), pp. 55-65.
Velichko, A.A. (ed.), 2002: Dynamics of terrestrial landscape components and inland and marginal seas of Northern Eurasia during the last 130,000 years. GEOS, Moscow, Russia, 296pp.
Velichko, A.A., O.K. Borisova, E.M. Zelikson, and T.D. Morozova, 2004: Changes in vegetation and soils of the East European Plain to be expected in the 21st century due to the antropogenic changes in climate. Geographia Polonica, 77(2), pp. 35-45.
Velichko, A.A., O.K. Borisova, E.M. Zelikson, and V.P. Nechaev, 1995: Permafrost and vegetation response to global warming in North Eurasia. In: Biospheric feedbacks in the global climate system - will the warming feed the warming? [Woodwell, G.M., and F.T. Mackenzie (eds.)]. Oxford University Press, New York, Oxford, pp. 134-156.
Velichko, A.A., N. Catto, A.N. Drenova, V.A. Klimanov, K.V. Kremenetski, and V.P. Nechaev, 2002: Climate changes in East Europe and Siberia at the late glacial- holocene transition. Quaternary International, 91(1), pp. 75-99.
Velichko, A.A., E.Y. Novenko, V.V. Pisareva, E.M. Zelikson, T. Boettger, and F.W. Junge, 2005: Vegetation and climate changes during the Eemian interglacial in Central and Eastern Europe: comparative analysis of pollen data. Boreas, 34(2), pp. 207-219.
Verburg, P., R.E. Hecky, and H. Kling, 2003: Ecological consequences of a century of warming in Lake Tanganyika. Science, 301(5632), pp. 505-507.
Verburg, P.H., J.E. Schulp, N. Witte, and A. Veldkamp, 2006: Downscaling of land use changes to assess the dynamics of European landscapes. Agriculture, Ecosystems and Environment, 114(1), pp. 39-56.
Vicente-Serrano, S.M., J.C. Gonzalez-Hidalgo, M. de Luis, and J. Raventos, 2004: Drought patterns in the Mediterranean area: the Valencia region (eastern Spain). Climate Research, 26(1), pp. 5-15.

Villalba, R., and T.T. Veblen, 1997: Regional patterns of tree population age structures in northern Patagonia: Climatic and disturbance influences. Journal of Ecology, 85(2), pp. 113-124.
Villers-Ruiz, L., and I. Trejo-Vazquez, 1998: Impact of climatic change in forests and natural protected areas of Mexico. Interciencia, 23(1), pp. 10-+.
Virtanen, T., S. Neuvonen, A. Nikula, M. Varama, and P. Niemelä, 1996: Climate change and the risks of Neodiprion sertifer outbreaks on Scots pine. Silva Fennica, 30(2-3), pp. 169-177.
Visser, M.E., C. Both, and M.M. Lambrechts, 2004: Global climate change leads to mistimed avian reproduction. Advances in Ecological Research, 35, pp. 89-110.
Vitousek, P.M., D.A. C.m, L.L. Loope, M. Rejmanek, and R. Westbrooks, 1997a: Introduced species: a significant component of human-caused global change. New Zealand Journal of Ecology, 21(1), pp. 1-16.
Vitousek, P.M., H.A. Mooney, J. Lubchenco, and J.M. Melillo, 1997b: Human domination of Earth's ecosystems. Science, 277(25. Jul.), pp. 494-499.
Vlassova, T.K., 2002: Human impacts on the Tundra-Taiga zone dynamics: the case of the Russian Lesotundra. Ambio, Special Report 12, pp. 30-36.
Volney, W.J.A., and R.A. Fleming, 2000: Climate change and impacts of boreal forest insects. Agriculture, Ecosystems and Environment, 82(1-3), pp. 283-294.
Von Maltitz, G.P., R.J. Scholes, B. Erasmus, and A. Letoalo, 2007: Adapting conservation strategies to accommodate impacts of climate change. In: AIACC Adaptation Synthesis p. (In press).
Walker, M.D., C.H. Wahren, R.D. Hollister, G.H.R. Henry, L.E. Ahlquist, J.M. Alatalo, M.S. Bret-Harte, M.P. Calef, T.V. Callaghan, A.B. Carroll, H.E. Epstein, I.S. Jonsdottir, J.A. Klein, B. Magnusson, U. Molau, S.F. Oberbauer, S.P. Rewa, C.H. Robinson, G.R. Shaver, K.N. Suding, C.C. Thompson, A. Tolvanen, O. Totland, P.L. Turner, C.E. Tweedie, P.J. Webber, and P.A. Wookey, 2006: Plant community responses to experimental warming across the tundra biome. Proceedings of the National Academy of sciences of the United States of America, 103(5), pp. 1342-1346.
Walsh, J.E., and M.S. Timlin, 2003: Northern Hemisphere sea ice simulations by global climate models. Polar Research, 22(1), pp. 75-82.
Walther, G.R., C.A. Burga, and P.J. Edwards (eds.), 2001: "Fingerprints" of climate change - adaptative behavior and shifting species ranges. Kluwer, New York a.o., 329pp.
Walther, G.R., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J.M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein, 2002: Ecological responses to recent climate change. Nature (London), 416(6879), pp. 389-395.
Wand, S.J.E., G.F. Midgley, M.H. Jones, and P.S. Curtis, 1999: Responses of wild C4 and C3 grass (Poaceae) species to elevated atmospheric CO2 concentration: a meta-analytic test of current theories and perceptions. Global Change Biology, 5(6), pp. 723-741.
Wang, G.L., and E.A.B. Eltahir, 2002: Impact of CO2 concentration changes on the biosphere-atmosphere system of West Africa. Global Change Biology, 8(12), pp. 1169-1182.
Wang, S.Q., J.Y. Liu, G.R. Yu, Y.Y. Pan, Q.M. Chen, and K.R.L.J.Y. Li, 2004a: Effects of land use change on the storage of soil organic carbon: A case study of the Qianyanzhou Forest Experimental Station in China. Climatic Change, 67(2-3), pp. 247-255.
Wang, X.L.L., F.W. Zwiers, and V.R. Swail, 2004b: North Atlantic Ocean wave climate change scenarios for the twenty-first century. Journal of Climate, 17(12), pp. 2368-2383.
Wanner, H., R. Rickli, E. Salvisberg, C. Schmutz, and M. Schüepp, 1997: Global climate change and variability and its influence on Alpine climate - Concepts and observations. Theoretical and Applied Climatology, 58, pp. 221-243.
Warburton, M., R.E. Schulze, and M. Maharaj, 2005: Is South Africa's temperature changing? An analysis of trends from daily records, 1950-2000. WRC 1430/1/05, Climate change and water resources in southern Africa.
Warner, T.T., 2004: Desert meteorology. Cambridge University Press, Cambridge, 595pp.
Warren, R., 2006: Impacts of global climate change at different annual mean global temperature increases. In: Avoiding dangerous climate change [Schellnhuber, H.J.p.C.W., N. Nakicenovic, T.

Wigley, and G. Yohe (eds.)]. Cambridge University Press, Cambridge, UK, pp. 93-131.
Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D.J. Dokken (eds.), 2000: Land use, land-use change, and forestry - A special report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, 377pp.
Weltzin, J.F., S.D. Bridgham, J. Pastor, J.Q. Chen, and C. Harth, 2003: Potential effects of warming and drying on peatland plant community composition. Global Change Biology, 9(2), pp. 141-151.
Weltzin, J.F., C. Harth, S.D. Bridgham, J. Pastor, and M. Vonderharr, 2001: Production and microtopography of bog bryophytes: response to warming and water-table manipulations. Oecologia, 128(4), pp. 557-565.
Weltzin, J.F., J. Pastor, C. Harth, S.D. Bridgham, K. Updegraff, and C.T. Chapin, 2000: Response of bog and fen plant communities to warming and water-table manipulations. Ecology, 81(12), pp. 3464-3478.
Wernli, H., S. Dirren, M.A. Liniger, and M. Zillig, 2002: Dynamical aspects of the life cycle of the winter storm 'Lothar' (24-26 December 1999).
Quarterly Journal of the Royal Meteorologial Society, 128(580), pp. 405-429.
Wessel, W.W., A. Tietema, C. Beier, B.A. Emmett, J. Penuelas, and T. Riis-Nielsen, 2004: A qualitative ecosystem assessment for different shrublands in western Europe under impact of climate change. Ecosystems, 7(6), pp. 662-671.
White, A., M.G.R. Cannell, and A.D. Friend, 1999: Climate change impacts on ecosystems and the terrestrial carbon sink: a new assessment. Global Environmental Change, 9(Supplement 1), pp. S21-S30.
White, A., M.G.R. Cannell, and A.D. Friend, 2000a: CO2 stabilization, climate change and the terrestrial carbon sink. Global Change Biology, 6(7), pp. 817-833.
White, A., M.G.R. Cannell, and A.D. Friend, 2000b: The high-latitude terrestrial carbon sink: a model analysis. Global Change Biology, 6(2), pp. 227-245.
White, T.A., B.D. Campbell, P.D. Kemp, and C.L. Hunt, 2000c: Sensitivity of three grassland communities to simulated extreme temperature and rainfall events. Global Change Biology, 6(6), pp. 671-684.
Whitlock, C., S.L. Shafer, and J. Marlon, 2003: The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management. Forest Ecology and Management, 178(1-2), pp. 5-21.
Wichmann, M.C., F. Jeltsch, W.R.J. Dean, K.A. Moloney, and C. Wissel, 2003: Implication of climate change for the persistence of raptors in arid savanna. OIKOS, 102(1), pp. 186-202.
Wicks, T.E., and P.J. Curran, 2003: Flipping forests: estimating future carbon sequestration of the boreal forest using remotely sensed data. International Journal of remote sensing, 24(4), pp. 835-842.
Wikelski, M., and C. Thom, 2000: Marine iguanas shrink to survive El Nino - Changes in bone metabolism enable these adult lizards to reversibly alter their length. Nature (London), 403(6765), pp. 37-38.
Wilby, R.L., S.P. Charles, E. Zorita, B. Timbal, P. Whetton, and L.O. Mearns, 2004: Guildelines for use of climate scenarios developed from statistical downscaling methods. IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA). Intergovernmental Panel on Climate Change (IPCC) - ata Distribution Centre (DDC), Norwich, UK, Hamburg, Germany, and New York, USA, 27pp.
Wiley, J.W., and J.M. Wunderle, Jr., 1994: The effects of hurricanes on birds, with special reference to Caribbean islands. Bird Conservation International, 3(4), pp. 319-349.
Williams, A.A.J., D.J. Karoly, and N. Tapper, 2001: The sensitivity of Australian fire danger to climate change. Climatic Change, 49(1-2), pp. 171-191.
Williams, M.A., C.W. Rice, A. Omay, and C. Owensby, 2004a: Carbon and nitrogen pools in a tallgrass prairie soil under elevated carbon dioxide. Soil Science Society of America Journal, 68(1), pp. 148-153.
Williams, P., L. Hannah, S. Andelman, G. Midgley, M. Araujo, G. Hughes, L. Manne, E. Martinez-

Meyer, and R. Pearson, 2005: Planning for climate change: Identifying minimum-dispersal corridors for the Cape proteaceae. Conservation Biology, 19(4), pp. 1063-1074.
Williams, R.J., L.B. Hutley, G.D. Cook, J. Russell-Smith, A. Edwards, and X.Y. Chen, 2004b: Assessing the carbon sequestration potential of mesic savannas in the Northern Territory, Australia: approaches, uncertainties and potential impacts of fire. Functional Plant Biology, 31(5), pp. 415-422.
Williams, S.E., E.E. Bolitho, and S. Fox, 2003: Climate change in Australian tropical rainforests: an impending environmental catastrophe. Proceedings of the Royal Society of London - Series B Biological Sciences, 270(1527), pp. 1887-1892.
Willig, M.R., D.M. Kaufman, and R.D. Stevens, 2003: Latitudinal gradients of biodiversity: Pattern, process, scale, and synthesis. Annual Review of Ecology Evolution and Systematics, 34, pp. 273-309.
Wilmking, M., G.P. Juday, V.A. Barber, and H.S.J. Zald, 2004: Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds. Global Change Biology, 10(10), pp. 1724-1736.
Winder, M., and D.E. Schindler, 2004: Climatic effects on the phenology of lake processes. Global Change Biology, 10(11), pp. 1844-1856.
Wingfield, J.C., G. Ramos-Fernandez, A.N.D. La Mora, and H. Drummond, 1999: The effects of an "El Nino" southern oscillation event on reproduction in male and female blue-footed boobies, Sula nebouxii. General and Comparative Endocrinology, 114(2), pp. 163-172.
Winnett, S.M., 1998: Potential effects of climate change on US forests: a review. Climate Research, 11(1), pp. 39-49.
Winslow, J.C., J. Hunt, E. Raymond, and S.C. Piper, 2003: The influence of seasonal water availability on global C3 versus C4 grassland biomass and its implications for climate change research. Ecological Modelling, 163(1-2), pp. 153-173.
Woodward, F.I., and M.R. Lomas, 2001: Integrating fluxes from heterogeneous vegetation. Global Ecology and Biogeography, 10(6), pp. 595-601.
Woodward, F.I., and M.R. Lomas, 2004a: Simulating vegetation processes along the Kalahari transect. Global Change Biology, 10(3), pp. 383-392.
Woodward, F.I., and M.R. Lomas, 2004b: Vegetation dynamics - simulating responses to climatic change. Biological reviews of the Cambridge Philosophical Society, 79(3), pp. 643-670.
Woodwell, G.M., 2004: Mountains: top down. Ambio, 35-38(Suppl. 13Suppl. 13), pp. 35-38.
Woodwell, G.M., F.T. Mackenzie, R.A. Houghton, M. Apps, E. Gorham, and E. Davidson, 1998: Biotic feedbacks in the warming of the Earth. Climatic Change, 40(3-4), pp. 495-518.
Wooldridge, S., T. Done, R. Berkelmans, R. Jones, and P. Marshall, 2005: Precursors for resilience in coral communities in a warming climate: a belief network approach. Marine Ecology. Progress Series, 295, pp. 157-169.
Woomer, P.L., A. Toure, and M. Sall, 2004: Carbon stocks in Senegal's Sahel transition zone. Journal of Arid Environments, 59(3), pp. 499-510.
World Commission on Dams, 2000: Dams and development: a new framework for decision-making. Earthscan, London a.o., 404pp.
Wotton, B.M., D.L. Martell, and K.A. Logan, 2003: Climate change and people-caused forest fire occurrence in Ontario. Climatic Change, 60(3), pp. 275-295.
Wright, S.J., O. Calderón, A. Hernandéz, and S. Paton, 2004: Are lianas increasing in importance in tropical forests? A 17-year record from Panama. Ecology, 85(2), pp. 484-489.
Wullschleger, S.D., and R.J. Norby, 2001: Sap velocity and canopy transpiration in a sweetgum stand exposed to free-air CO2 enrichment (FACE). New Phytologist, 150(2), pp. 489-498.
Xenopoulos, M.A., D.M. Lodge, J. Alcamo, M. Marker, K. Schulze, and D.P. Van Vuuren, 2005: Scenarios of freshwater fish extinctions from climate change and water withdrawal. Global Change Biology, 11(10), pp. 1557-1564.
Xoplaki, E., J.F. Gonzalez-Rouco, D. Gyalistras, J. Luterbacher, R. Rickli, and H. Wanner, 2003: Interannual summer air temperature variability over Greece and its connection to the large-scale

atmospheric circulation and Mediterranean SSTs 1950-1999. Climate Dynamics, 20(5), pp. 537-554.

Xu, D.Y., and H. Yan, 2001: A study of the impacts of climate change on the geographic distribution of Pinus koraiensis in China. Environment International, 27(2-3), pp. 201-205.

Yoccoz, N.G., and R.A. Ims, 1999: Demography of small mammals in cold regions: The importance of environmental variability. In: Animal Responses to Global Change in the North [Hofgaard, A., J.P. Ball, K. Danell, and T.V. Callaghan (eds.)]. pp. 137-144.

Zalakevicius, M., and S. Svazas, 2005: Global climate change and its impact on wetlands and waterbird populations. Acta Zoologica Lituanica, 15(3), pp. 215-217.

Zavarzin, G.A., and V.N. Kudeyarov, 2006: The soil as the main source of CO2 and reservoir of the organic carbon in the territory of Russia. Global Change Biology, 76(1), pp. 14-29 (in Russian).

Zebisch, M., F. Wechsung, and H. Kenneweg, 2004: Landscape response functions for biodiversity - assessing the impact of land-use changes at the country level. Landscape and Urban Planning, 67(1-4), pp. 157-172.

Zeebe, R.E., and D. Wolf-Gladrow, 2001: CO2 in seawater: equilibrium, kinetics, isotopes. Elsevier, Amsterdam, 346pp.

Zha, Y., J. Gao, and Y. Zhang, 2005: Grassland productivity in an alpine environment in response to climate change. Area, 37(3), pp. 332-340.

Zhang, W., K.M. Parker, Y. Luo, S. Wan, and L.L.H.S. Wallace, 2005: Soil microbial responses to experimental warming and clipping in a tallgrass prairie. Global Change Biology, 11(2), pp. 266-277.

Zierl, B., and H. Bugmann, 2005: Global change impacts on hydrological processes in Alpine catchments. Water Resources Research, 41(2)

Ziska, L.H., T.B. Moya, R. Wassmann, O.S. Namuco, R.S. Lantin, J.B. Aduna, E. Abao, K.F. Bronson, H.U. Neue, and D. Olszyk, 1998: Long-term growth at elevated carbon dioxide stimulates methane emission in tropical paddy rice. Global Change Biology, 4(6), pp. 657-665.

Zockler, C., and I. Lysenko, 2000: Waterbirds on the edge. WCMC Biodiversity Series No. 11, UNEP/WCMC, 27pp.