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Adaptations of Forests to Climate Change:

A Multidisciplinary Review

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ABSTRACT

Forests around the world are widely expected to face significant pressures from climate change over the coming century. Although the magnitudes of the projected temperature rises and precipitation changes are still uncertain, modelling based on mean figures shows that ecological, economic and social disruptions are likely.

Ecological effects range from phenological changes and extensions of growing seasons to widespread forest structural changes, species migrations and extinctions. Warmer climates are overall expected to have a positive influence on the wood products industries, although some regions are predicted to benefit more than others and some may be disadvantaged. The social effects of climate change are highly uncertain, and projects to strengthen community resilience and reduce vulnerability are recommended.

CONTENTS

1. INTRODUCTION

Over the past decade several major reports have been produced that deal with the possible threats to forest environments in different parts of the world (WCMC, 1999; USDA, 2000; SilviStrat, 2005; IPCC, 2007b). This review will briefly summarise the pertinent points of these reports, and provide further details and references more closely aligned with the topic 'Adaptations of Forests to Climate Change'. The work also builds on earlier reviews by Kräuchi (1993), Winnett (1998), Joyce and Nielson (eds, 2000), Hyvönen et al. (2007), Clark (2007), Kleine and Roberts (2007) and Sohngen et al. (2007) and extracts forest-specific material from Parmesan and Galbraith (2004), TROFCCA (2005) and Parmesan (2006). This paper will also extend prior reviews by combining the physical science review with discussion of economic and social impacts. Headings in this document are chosen to align with the areas of specialisation listed in the document "Selection Criteria and Process" of the Expert Panel on Adaptation of Forests to Climate Change. This Expert Panel is currently (January 2008) being assembled by the International Union of Forest Research Organisations (IUFRO) in the framework of the Collaborative Partnership on Forests' Joint Initiative on Science and Technology.

Multidisciplinary reviews are rare, probably due to the impossibility of doing full justice to all the topics of discussion, and to the differences in basic assumptions and language used in different fields (Dewulf et al., 2007). This review does not present itself as a definitive review of each discipline, but is rather a roundup of each, intended to give a grounding to experts from other fields and stimulate cross-disciplinary discussion. It aims to serve as a guide to current thinking and as an introduction to each area of specialization for experts of different research fields. For reasons of space, topics that have recently been comprehensively reviewed elsewhere are only treated briefly, while less well reviewed subject areas are discussed in greater depth. The paper was researched using literature sourced through Google and ISI Web of Science, in October and November 2007.

The need for a review of this nature (and for the Expert Panel) is underlined by the fact that the European Environmental Agency (EEA) excluded forestry from its 2004 report on the impacts of changing climate (EEA, 2004) due to a lack of information. This is in spite of the fact that the climatic changes expected in the coming century are of such a magnitude that, based on historical precedent, substantial vegetation change is to be expected (Chapin et al. 2004).

2. CLIMATOLOGY, CLIMATE MODELLING AND SCENARIOS

2.1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) recently released their fourth assessment report, known as AR4. Their conclusions regarding the causes and extent of global climate change are similar to those in the third assessment report (TAR), but in AR4 the IPCC has committed to a greater degree of certainty in their major projections. A rise in average global temperatures of between 2.0 – 4.5 degrees is likely, and a rise of less than 1.5 degrees is very unlikely (IPCC, 2007b). The degree of climate change is expected to depend largely on the levels of greenhouse gas emissions over the ensuing century. The IPCC has produced a range of scenario modelling (Figure 1) to show the sensitivity of global temperatures to various economic growth scenarios and CO_2 emission patterns (Meehl et al., 2007).

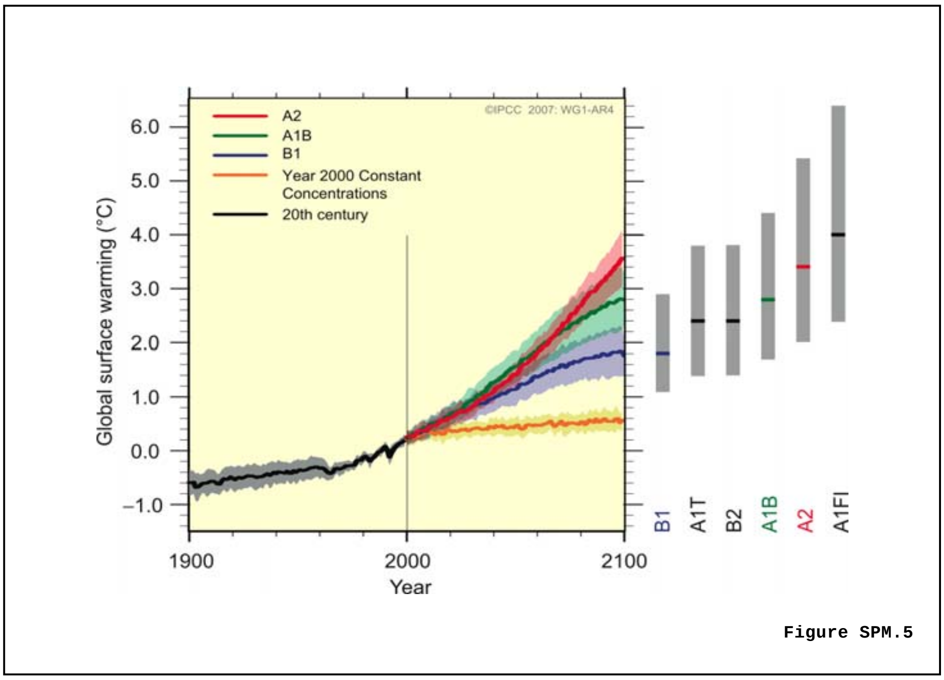

Figure 1. Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assesses for the six SRES marker scenarios. The assessment of the best estimate and the likely ranges in the grey bars includes the AOGCMs in the left of the figure, as well as results from a hierarchy of independent models and observational constraints. Reproduced from IPCC (2007b).

The anticipated temperature rises are not expected to be globally consistent (Christensen et al., 2007). The bulk of the warming is expected in the northern polar regions and the least in the higher latitudes of the Southern Ocean and the North Atlantic. Warming over land surface is expected to be greater than over oceans, and night-time temperatures to rise more than daytime temperatures do. Heat waves will be more common and more intense, most notably in central Europe, western USA and East Asia. Effects on rainfall patterns are expected to vary, with increases in the higher latitudes and the equatorial belt but decreases in the sub-tropical regions. Extreme rainfall events are likely to be more frequent (see also Groisman et al., 2005), particularly in northern Europe and the Antipodes. Increased dry-season droughts are likely in mid-latitude areas such as the Mediterranean and Central America. The frequency of tropical cyclones may be less, but those that do occur will be more intense. Storms with intense winds are likely to be larger and more frequent in central Europe and the North Atlantic.

2.2. ENSO

Regional climate patterns in many areas are strongly linked to cyclic oceanic temperature patterns such as the El Nino-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), but the interactions of global climate change with ENSO and NAO are not clear (Le Treut et al., 2007). These patterns have been shown in the past to have a very strong influence on drought and severe fires in Australia, floods in Peru, dry periods in the North American southwest and other regional climate effects (Fagan, 2000). These regional effects can sometimes have very significant climate effects, but are not related to global climate variation. The European Medieval Warm Period (MWP) and Little Ice Age (LIA) are good examples of this; highly significant regional effects that had little bearing on global averages (Mann, 2007). The degree to which the effects of global climate change on forests will be masked or enhanced by regional variability is not known.

There is some evidence that ENSO was weaker in the early Holocene, and that the transition to stronger patterns occurred in the past few thousand years (Jansen et al., 2007). Cane (2005) discusses the various attempts at modelling ENSO, and while he expects that ENSO will behave differently under a higher global average temperature regime, is unable to conclude what those differences will be. Meehl et al. (2007) agree that there are no consistent indications for or against changes in ENSO frequency or intensity. Detecting long-tem changes in forest ecologies due to climate change is also often confounded by the influence of ENSO (Lewis et al., 2004).

2.3. Vegetation effects on climate

Current understandings of biogeochemical interactions and feedbacks between the atmosphere and land and water are reviewed for the IPCC by Denman et al. (2007). Feedback effects from forest to climate may be either biogeophysical (albedo and transpiration changes) or biogeochemical (atmospheric CO_2) (Brovkin et al., 2004). The two effects work in opposite directions; expanding forests would reduce global warming by sequestering more CO_2 but the increased transpiration would increase greenhouse and the lower albedo of the forest surface would also contribute to warming. The net effect of deforestation on global climate since 1000 AD was modelled by Brovkin et al. (2004) to be about .08 degrees of cooling, but regional effects were much more substantial. The end of the MWP and the relatively cool period until the mid-20th century has been attributed in part to the clearing of European forests that began over 1000 years ago (Goosse et al., 2006). Oleson et al. (2004) found that land use change may have been responsible for a more than 2.0 degree drop in potential summer temperatures over parts of the USA, due to increased albedo and transpiration and decreased surface roughness. Feddema et al. (2005) suggest that reforestation could contribute to higher temperatures in Europe and eastern North America.

The cooling effect of deforestation due to albedo decreases is pronounced in boreal areas (Brovkin et al., 2006), but in the tropics the reduced transpiration and surface roughness may lead to increased temperatures (Snyder et al., 2004; Feddema et al., 2005). Forest changes can also have significant hydrological effects, including runoff patterns, soil moisture levels, transpiration and cloudiness These issues may also have some impact on climate change (Denman et al., 2007), although the degree is often very uncertain.

2.4. Climate models

Climate modelling since the Third Assessment Report (IPCC, 2001) has taken a step forward in including atmospheric chemistry and the biogeochemical interactions of vegetation with the atmosphere, although at the time that AR4 was produced this was still very new, and results are often unclear. These newest techniques have so far not commonly been included in modelling studies (Randall et al., 2007).

AR4 is based on 23 climate models, including three produced in the late 1990s and nine each from 2004 and 2005. Much of the literature relating to the adaptations of forests to climate change was predicated on results from much earlier modelling. The climate scenarios produced in the TAR were occasionally criticized (reviewed in Jansen et al., 2007) and misgivings persist over AR4 (Fraser Institute, 2007), but there is no doubt that in combination, the IPCC suite of models represent the best available figures on which to base future biome modelling.

Global Circulation Models (GCMs) suffer from being very complex but still of coarse resolution and geographically very broad scale. The representation of regional climates in GCMs is often quite poor, particularly for precipitation (RealClimate, 2007). Although confidence in regional climate projections has increased since the TAR (Christensen et al., 2007), regional climate changes are highly variable, and are not well represented in GCMs (Bell et al., 2004). An increasingly common approach is to ‘nest’ regional climate models (RCMs) within GCMs (Schwierz et al. 2006).

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2.5. Local extreme events

Changes to forest biomes may be driven by changes in the intensity and frequency of climatic extremes moreso than by changes in global averages. As an example, the well-documented environmental and social effects of the European LIA occurred against a backdrop of a global climate only 0.2 degrees cooler than today (Salinger, 2005) The precise effects of historical extreme events can be difficult to determine from the palaeorecord, but the use of documentary evidence can often provide useful details of local events (Pfister et al., 2002). The use of local historical ecology (Swetman et al., 1999) can be useful to judge the effects of previous climatic extremes, and possibly to draw inferences for the future.

3. METHODOLOGIES AND TOOLS TO ASSESS IMPACTS AND VULNERABILITIES

3.1. Introduction

Vegetation modelling can give some indications of the characteristics of biomes under changed climate conditions and general predictions can be made about increased fire risks or insect attacks, but at present there appears to be no formalised method of assessing forest ecosystems' vulnerability to climate change. The high levels of scientific uncertainty are exacerbated by the need for subjective judgements regarding vulnerability assessment (Schneider et al., 2007)

3.2. Vegetation classification schemes

Vegetation classification schemes have been in use for several decades (Mueller-Dombois and Ellenberg, 1974), and more recently have evolved into sophisticated models vital for examining the interaction between vegetation and climate. Unfortunately no internationally consistently accepted classification for forests exists at a scale useful for modelling. Running et al. (1995) presented a hierarchical classification scheme involving 6 canopy-structure based classes, suitable for working with remotely sensed data. The six classes can be further broken down into 21 sub-classes (Nemani and Running, 1996). Another approach is that of a Growing Season Index (Jolly et al., 2005), to take into account various environmental factors and predict phenological responses to changing climatic conditions.

Digital vegetation maps suitable for use in climate modelling have been produced by the European Commission Joint Research Centre Institute for Environment and Sustainability (Bartholome et al., 2002) and the National Aeronautics and Space Administration International Satellite Land Surface Climatology Project Global Data Sets for Land-Atmosphere Models (NASA ISLSCP GDSLAM; described in Dang et al., 2007).

3.3. Vegetation models

Vegetation scenario models fall into three broad categories:

i) Biogeographical models such as the Holdridge Live Zone model (see Yates et al., 2000) and the Mapped Atmosphere-Plant-Soil System (MAPPS; Nielson 1995),
ii) Biogeochemical models like BIOME3 (Haxeltine and Prentice, 1996), and
iii) Statistical distribution models such as DISTRIB (Iverson and Prasad, 2001).

Biogeographical models are generally used to study the anticipated effects of climatic changes on biome range boundaries, but are not so useful at judging the health of those ecosystems (Winnett 1998; Pan et al., 2002). Models of this type use climate data and levels of constraining resources such as light, water or nutrients to anticipate the ecotype that will be present under such conditions. Biogeochemical models analyse the responses of vegetation to changes in environmental cycles (carbon, nutrients and water) to determine ecosystem productivity and carbon storage but these models are not spatially explicit and do not show ecosystem distributions (Winnett, 1998; Nightingale et al., 2004). Statistical models lack fine detail but are useful for broad initial studies, as they do not need the precise input data required by process models.

More recently, models such as MC1 (Bachelet et al., 2001) and BIOME4 (Kaplan et al., 2003) have been developed which include modules of both biogeographical and biogeochemical types, although earlier versions of the BIOME family did not take into account land-use issues (Sohngen et al., 2001). Many authors have pointed out the need for the feedback from land cover changes to be included in modelling. Pyke and Andelman (2007) reviewed the impacts of land use change on climate and discuss some opportunities for land use change as a means of climate manipulation.

Dynamic biome modelling (Peng, 2000) and Forest Landscape Simulation Models (FLSM; Scheller and Mladenoff, 2007) are steps forward in developing understandings of forest responses to climate change, but there appears to be a dearth or studies that investigate the precise mechanisms of change, and the implications of these changes in terms of forest ecologies at particular points in time.

4. IMPACTS ON FOREST ECOSYSTEMS

4.1. Introduction

Despite the greater sophistication of current Global Circulation Models (GCMs) and Global Vegetation Models (GVMs), the broad-scale global scenarios commonly presented now differ little from those given by Krauchi (1993). This implies a high degree of confidence in these results, but a useable level of detail is still lacking. The general themes of boreal expansion, drought stress in temperate regions and deciduous trees and conifers into alpine belts are common to most scenario modelling.

Palaeological and historical research can give hints as to what forests looked like in the late Holocene period, to perhaps give some indications as to what climax vegetation may be encouraged by warmer climatic conditions. A better understanding of pre-anthropogenically influenced forest ecologies may aid future planning in the face of climatic change (Flenley, 1998; Lynch et al., 2007).

Predictions for the adaptations of forests to climate change most often involve increased growth rates, tree-line movements, changes to forest species assemblages, increased fire incidence, more severe droughts in some areas, increased storm damage, increased insect and pathogen damage. More recent data is also showing evidence of changes in forest phenology and growth.

This section will look firstly at the modelled changes to forest biomes that may be anticipated, and then at observed changes and records of change.

4.2. Predicted impacts

4.2.1. Structural Changes

4.2.1.1. Biome redistributions

Detailed modelling studies of biome redistributions have been carried out in many regions. A few of these are presented in table 2.

Nation/region	*Researcher*
India	Ravindranath et al. (2006)
VietNam	Booth et al. (1999)
Mexico	Castellanos (2006)
Austria	Lexer et al. (2002)
USA	VEMAP Members (1995) Bachelet et al. (2001) Bachelet and Neilson (2004)
Southern Sweden	Bradshaw et al. (2000)

Eastern USA	Iverson and Prasad (1998) Iverson and Prasad (2001)
Alaska	Bachelet et al. (2005)

Table 2. Regional biome redistribution studies.

Modelling of biome potential distribution generally shows decreases in the areas of tundra, tundra/taiga and arid lands, and increases in grassland, tropical broadleaf forest and temperate mixed forests (Malcolm 2003). All else being equal, warming will allow species to be grown at higher altitudes and latitudes than at present (Bachelet and Nielson 2000; Sykes and Prentice 1996), but species composition at the lower altitudes and latitudes may tend more towards temperate species.

A report produced by the European Forest Institute (EFI, 2000) contains the results of a pan-European survey of forest experts. As a rule, experts were of the opinion that increased temperatures would have a large positive impact on forest regeneration and growth in boreal areas. Drought would have a strong negative effect on forest regeneration in the Atlantic and Mediterranean regions, while fire would strongly negatively affect forest growth in the Continental zone. In temperate regions climate change is usually expected to have a positive influence on forests.

4.2.1.2. Migration rates

There are concerns expressed in the literature and formal reports that boreal species migration will lag behind the poleward shift of climatic zones (IPCC 2007a; Lemmen and Warren (eds), 2004; EEA, 2004; IPCC, 2001; WCMC 1999; Winnett, 1998). Hansen et al. (2001) cite Davis and Zabinski (1992) in support of this thesis. This is based on the recorded current rates of species dispersal, which is generally very slow. The IPCC (2001) cite reports for species migration rates that will sees trees lag several centuries behind the moving climate envelope, but this is not universally accepted. Higgins et al. (n.d.) point out that species migrations are driven by long-distance dispersal mechanisms, which are often quite rare and are ignored in many studies of species dispersal. Huntley (2003) suggests that because propagules of tree species are already spread well beyond present tree-lines, the rate of migration is not expected to be a limitation. Following a 10-year study into species dispersal in the Appalachians Ibanez et al. (2007) concluded that there was no danger of species extinctions except at higher altitudes. Tinner and Lotter (2001) suggest that the rate of postglacial expansions was controlled by climate, not by migration rates. The classic example of Reid's Paradox (de Jong and Klinkhammer, 2005) describes how oak trees must have migrated, on average, one kilometre per tree generation following the last glacial maximum.

4.2.1.3. Cloud forests

Cloud forests are particularly vulnerable to climate change, as they occupy small niches near the top of tropical mountains and have limited potential for upwards migration. The unique reliance of this ecotype on cloud level as well as particular temperature and rainfall values makes them particularly sensitive to climatic changes (Loope and Giambelluca, 1998). Although the climatic/altitudinal niche for cloud forests could be expected to move upwards (accompanied by increased competitive pressures from lower altitude species), pressures from the upper boundaries are also possible, in the form of increased fire risk (Hemp, 2005).

4.2.1.4. Tropical forests

Modelling scenarios generally show a lower rate of warming in tropical areas, and there is little consensus on precipitation changes. Moisture stresses and fires could potentially have serious deleterious effects on tropical forests, particularly in Amazon (Fearnside, 2004). Conversely, increasing rainfall could favour forest expansion into savannah regions (Mayle et al., 2007).

4.2.1.5. Mangroves

Mangroves are a unique forest assemblage, in that they will be directly affected by rising sea-levels. Palaeological studies have found that mangrove forests may cope with rates of sea level rise of up to 1 mm per year through peat accumulation, but higher rates of rise will cause a loss of forest area (Ellison 2003). Mangroves have also been found to move inland in response to rising sea levels in the past, but in many cases now this move will be constrained by human settlement (WCMC 1999).

4.2.1.6. Temperate forests

The potential area of temperate forests is generally expected to increase, through a poleward expansion into formerly boreal forest regions due to increased temperature (Bradshaw et al., 2000; Hansen et al., 2001; Soja et al., 2007) and possibly an expansion into savannah or grasslands in regions with increasing precipitation (Bachelet et al., 2001). Particular forest assemblages in many areas occupy quite small climatic niches. In Australia for example, 41% of 819 *Eucalyptus* species are within 2 degrees of being outside their climatic zone (Hughes et al., 1996). Hughes (2003) describes modelling that shows that two degrees of warming would move 100% of the bioclimates of *Acacia* species.

4.2.1.7. Landscape fragmentation

Landscape fragmentation is often mentioned as a serious barrier to species migration (de Dios et al., 2007; Iverson et al., 2004; WCMC 1999) As Clark et al. (1998) point out however, presumable dispersal barriers such as Lake Michigan, the Baltic Sea and the North Sea do not seem to have prevented species from spreading from one side to the other. Collingham and Huntley (2000) modelled the dispersal of lime trees *Tilia cordata* in fragmented landscapes, and found a significant but non-linear relationship between habitat availability and migration rates. Critical values of habitat availability were between 10 and 25% of the landscape, with migration rates relatively stable above these values but dropping sharply below. Forests however have shown themselves to be excellent colonisers of formerly fragmented countryside, and many of today's forests in central Europe and North America were established in the 17^{th} and 18^{th} centuries on abandoned agricultural land. (Hyvönen et al., 2007).

4.2.1.8. Disturbance regimes

Most of the biome distribution modelling above revolves around fitting forest assemblages into new climatic niches in particular areas, taking into account altered temperature and precipitation conditions and biological features of the species. Average temperatures however may be less important than altered disturbance regimes, through fire, pest and pathogens or other extreme events. Increased disturbance rates may increase a forest's ability to adapt to changes climatic conditions by speeding up successional processes (Overpeck et al 1990), and forests have often shown themselves to be a resilient ecological structure (Chapin et al., 2004).

Although there is a growing level of confidence amongst scientist that average global temperatures will rise, and some progress made on regional climate scenarios, the modelling of extreme events is still highly problematic. It is these extreme events that, either alone or in combination with other disturbance mechanisms, will have the greatest impact on forest ecosystems. Throughout evolutionary history forests have moved or adapted in response to climate changes, changed fire regimes, new pest outbreaks and large-scale land-clearing, and have evolved methods to cope with these disturbances. The common understanding is that biomes in the past have only had to deal with gradual change, and so have had millennia or more to adapt. It may be however that biomes react in response to 'tipping-points' or shifting states (Chapin et al., 2004), rather than with a gradual adaptation. The exact timing of these tipping-points is unknown, but doubtlessly in most cases would be tied to changes in disturbance regimes.

4.2.2. Fire Science

Fires are an integral part of many forest ecologies, and have always been fundamental in shaping forest structures and assemblages (Bond et al., 2005), (Bowman, 2005), (Lynch et al., 2007). Fires have effects on tree mortality, germination, soil ecology, nutrient cycling, ecological heterogeneity and species succession (Dale et al., 2001). Fire may also be linked with other disturbances such as windthrow and insect damage (Flannigan et al., 2000). Human efforts aimed at fire suppression have contributed to altered fire regimes in many areas, leading to an increase in the number of intense, stand replacing fires (Sakulich and Taylor, 2007; Fernandes and Rigolot, 2007).

Fire regimes are strongly interlinked with climate changes (Whitlock et al., 2003; Meyer and Pierce, 2003; Taylor and Beaty, 2005), and so it is not surprising that many researchers are predicting changes in the occurrence and severity of forest fires in many regions. Williams et al. (2001) and Hughes (2003) reviewed the predicted impacts of climate change in Australia, and expect increased fuel loadings, drier fuels and increased dangerous fire weather. Lemmen and Warren (eds, 2004) reviewed model predictions for Canada, and found expectations of decreased fire frequency in parts of the eastern boreal forest, but increases elsewhere. Flannigan et al. (2000) stress that increased temperatures alone do not necessarily mean that more fires will occur; several other climatic and non-climatic factors are also involved such as ignition sources, fuel loads, vegetation characteristics, rainfall, humidity, wind, topography, landscape fragmentation and management policies. Taking these factors into account Flannigan et al. (2005) reviewed fire predictions for North America and suggest that overall increases in area burned may be in the order of 74-118% by the end of the 21st century. Bond (2003) however suggests that increased growth of woody plants under elevated CO_2 levels may enable them to reach fire-proof height earlier, increasing tree cover in African savannahs.

Torn et al. (1998) investigated the likely effects of climate change on fires in California, with particular reference to the implications for insurance companies. They expect both the number of escaped fires and the areas burned in contained fires to rise, particularly in sparsely settled chaparral scrub regions.

4.2.3. Pests and pathogens

4.2.3.1. Weeds

A rapidly changing climate will suit species that can spread quickly and are suited to a wide range of climatic conditions (Dukes 2003). Many invasive species have these traits, and an increase in weed problems is likely in many regions. In greenhouse trials of increased temperature and irradiance, blackberry (*Rubus fruticosus* was found to inhibit the germination of beech *Fagus sylvatica*, where under control conditions or without increased irradiance no inhibition was found (Fotelli et al., 2005). Unpredictable effects like this could have serious implications, in this case, in southeastern Australia where blackberry is a serious environmental weed.

4.2.3.2. Insects

Insects can cause considerable damage to forests, and major infestations can alter the carbon sequestration of forest stands or cause stand-replacement level disturbances (Volney and Fleming, 2000). Neuvonen et al. (1999) discuss the outbreaks of a sawfly *Neodiprion streifer* in Scots pine forests in northern Europe, and autumn moth *Epirrita autumnata* in boreal Fennoscandia. In both cases the populations of the pest species are normally controlled by low winter temperatures killing eggs. Rising winter temperatures is expected to cause an increase in the number and severity of outbreaks of these forest pests.

Large scale pest disturbances can change a forest's structure, as was found on the Kenai Peninsular of Alaska following the spruce beetle *Dendroctonus rufipennis* outbreaks of the 1990s (Boucher and Mead, 2006). Regions with a high spruce mortality were found to be regenerating with a higher proportion of grasses and woody shrubs, and spruce regeneration was limited. Insect attacks may also be linked with other disturbance mechanisms. In central Europe serious infestations of spruce bark beetle *Ips typographus* followed the severe storms of the 1990s (Wermelinger, 2004).

4.2.3.3. Climate mapping

A comprehensive review of the likely impacts on North American forests from diseases' and herbivores' responses to climate change was published by Ayers and Lombardero (2000). Apart from pest's reduced overwintering mortality, they found that climate driven physiological changes in trees may also have an impact on levels of pest damage. Hicke et al. (2006) however modelled the anticipated spread of mountain pine beetle *Dendroctonus ponderosae* in the western United States under 5 degrees of climate change, and found that the impacts on forests were likely to be less. Hunt et al. (2006) provide an analysis of the projected range expansions of several exotic insect species in Canada.

Climate mapping may be useful to predict the potential spread of pests and pathogens (Baker at al. 2000), although the results should not be considered a definitive prediction as other factors (food or host availability, genetic variability, short-term weather fluctuations and dispersal vectors are also very important. Baker et al. (2000) suggest that future modelling of pest and pathogen spread resulting form climate change should follow established Pest Risk Assessment procedures (i.e., IPPC, 2005).

4.2.4. Physiological effects

Most chemical reactions are temperature sensitive, including photosynthetic processes. Saxe et al. (2001) reviewed studying plants' responses to elevated temperatures and found that, in general, rising temperatures increase photosynthesis up to an optimum and then further rises will reduce it. The 2-3 degree temperature rises anticipated for the coming century are expected to be beneficial for photosynthesis, but this effect may be negated by increased moisture stress in some regions. Saxe et al. (2001) also discussed issues of soil chemistry, phenology, genetics and frost hardiness and dormancy but concluded that considerable uncertainty still exists in these areas. The major impact of rising temperatures *per se* in boreal regions is likely to be the increased growing season length from earlier spring thaws (Hyvönen et al. 2007).

Increased growth of seedlings in enriched CO_2 environments have been recorded for many species, but the degree that this will translate to increased forest growth is debated. Asshof et al. (2006) found that CO_2 does not affect woody biomass in several European species. Lewis et al. (2004) report some evidence of increasing growth in tropical forest stands. A meta-analysis by Curtis and Wang (1998) showed responses to various levels of CO_2 enrichment ranging from slight growth inhibition to around 80% growth increases, with a mean increase in biomass under unstressed conditions of 31%. Individual studies have found responses ranging from 30% inhibition to 500% growth enhancement.

Most early CO_2 experiments were done on container-grown seedlings, but an increasing amount of data is now available for trees grown in open-top chambers (Norby et al., 1999) and through Free Air CO_2 Enrichment (FACE) experiments (Ainsworth and Long, 2005). The response of many Northern Hemisphere woody plant species to elevated CO_2 levels is well documented, and is reviewed in Joyce and Nungesser (2000). Raison et al. (2007) report significant growth increases in some northern Australian tree species. Overall, many questions still exist regarding the responses of different species in different assemblages under different growing conditions (Karnosky, 2003; Kohut, 2003). The physiological responses of forests lead into their overall growth rates, commonly expressed as Net Primary Productivity (NPP).

The NPP of a forest is the total increase in growth, as measured by grams of carbon per unit area. As a general rule, NPP is held to increase with increases in temperature, CO_2 or moisture, up to very high temperatures or saturated conditions (Malcolm and Pitelka, 2000). The increase in NPP will depend largely on the impacts of climate change on nitrogen mineralisation and uptake. Changes in disturbance regimes and soil moisture levels are expected to have a major impact, but all else being equal then growth responses under anticipated levels of climate warming are expected to be positive (Saxe et al., 2001). Joyce and Nungesser (2000) report a projected global increase in NPP of between 17.8 and 20.6%, depending on climate scenarios.

For forests in the conterminous United States, the predicted range is 8.0 – 29.6%. Chapin et al. (2004) however point out that white spruce in Alaska is expected to have zero growth under a 2 degree rise, due to moisture stress. Clark (2007) reviews several studies that project reduced productivity in tropical forests.

4.3. Past and current observations

4.3.1. Palaeological records

The Eocene epoch (55 million to 34 million years ago) was noted for extensive tropical and warm temperate forests covering most of the world's northern land masses (Utescher and Mosbrugger, 2007). CO2 levels in this period are disputed, and estimates range from their being 1 to 6.5 times that of today (Jahren, 2007)

Many authors have studied forest assemblages from the Holocene period, in an attempt to determine the most recent warm climatic period without anthropogenic influence (Theurillat and Guisan, 2001). Several warm periods in the Holocene have been identified for different regions, and Hoek (2001) gives details of vegetation responses to rapid (within a few years) climate warming 14.7 and 11.5 thousand years ago. In northern Europe and northwest America, the warmest period may have been between 7000 and 5000 years ago (Jansen et al., 2007)

Most of northern Russia was forested to the Arctic coast ~ 9000 to 4000 years ago, suggesting a regional temperature 2.5-7.0 degrees warmer than today's (MacDonald et al., 2000). Tree population densities in Finland have been shown to have peaked at around 3000-1750 BC, and again in the period 900-1150AD (Helama et al., 2005).

West African pollen records were reviewed by Vincens et al. (1999), who found forest expansion to approximately 3000 years ago, followed by a period of increasing aridification and forest reduction. A new phase of continuing forest expansion is noted from 900-600 years ago.

Tinner and Lotter (2001) studied European vegetation responses to a major rapid cooling ~8.2 thousand years ago, and found that hazel *Corylus avellana* was replaced by pine *Pinus*, birch *Betula* and linden *Tilia* species with some invasion by beech *Fagus silvatica* and fir *Abies alba*. Reduced drought stresses may have allowed these other species to out-compete *Corylus*. Forest dynamics in northwestern Romania were examined by Feurdean (2005), using peat cores and pollen records to detail the successional changes from the post-glacial grasslands through to the anthropogenically affected oak *Quercus* forests of today. A similar study for parts of Korea was published by Chung et al. (2006), and for the Siskiyou Mountains of the northwestern USA by Briles et al. (2006) with particular reference to fire effects. Pollen records for the New York area show a dominance of *Pinus* from 800-1300 AD, followed by an increase of spruce *Picea* and Hemlock *Tsuga* species as climate cooled in the LIA (Pederson et al., 2005).

Cowling et al. (2001) compared palaeo-observations of forest species composition in Scandinavia with modelled results for the past 1500 years, and found good agreement for northern regions, showing that the relative abundance of *Pinus*, *Picea* and *Betula* species is climate determined, and alters in response to climate change. In the southern, nemoral regions modelling suggested that *Tilia* species should dominate, rather than the now present *Fagus* species. This lead Cowling et al. (2001) to conclude that the present dominance of *Fagus* at the Denmark study site is the result of anthropomorphic pressures prior to the 17th century. A review of palaeoecology and its methods was published by Ritchie (1995).

4.3.2. Recent

Although the latter part of the 21st century is widely held to be the warmest period globally for at least several millennia (Salinger, 2005; Mann, 2007) or possibly much longer (Thompson et al., 2006), there is forest evidence in some regions of warmer periods over the past thousand years. Mazepa (2005) studied tree-line changes in the Polar Ural Mountains, where the remains of forests 60 to 80 metres above the present tree-line are still evident, dating back as far as 720AD. Several climate-connected tree-line advancements are evident, in the 11th to 13th centuries, the 18th century and the latter part of the 21st century. Similarly, evidence exists of advanced tree-lines in the MWP in the southern Canadian Rockies (Luckman, 1994) and Quebec (Arseneault and Payette, 1997). In a modelling study of European climates over the past 1000 years Goosse et al. (2006) conclude that it cannot be stated with certainty that European temperatures are higher now than in the MWP.

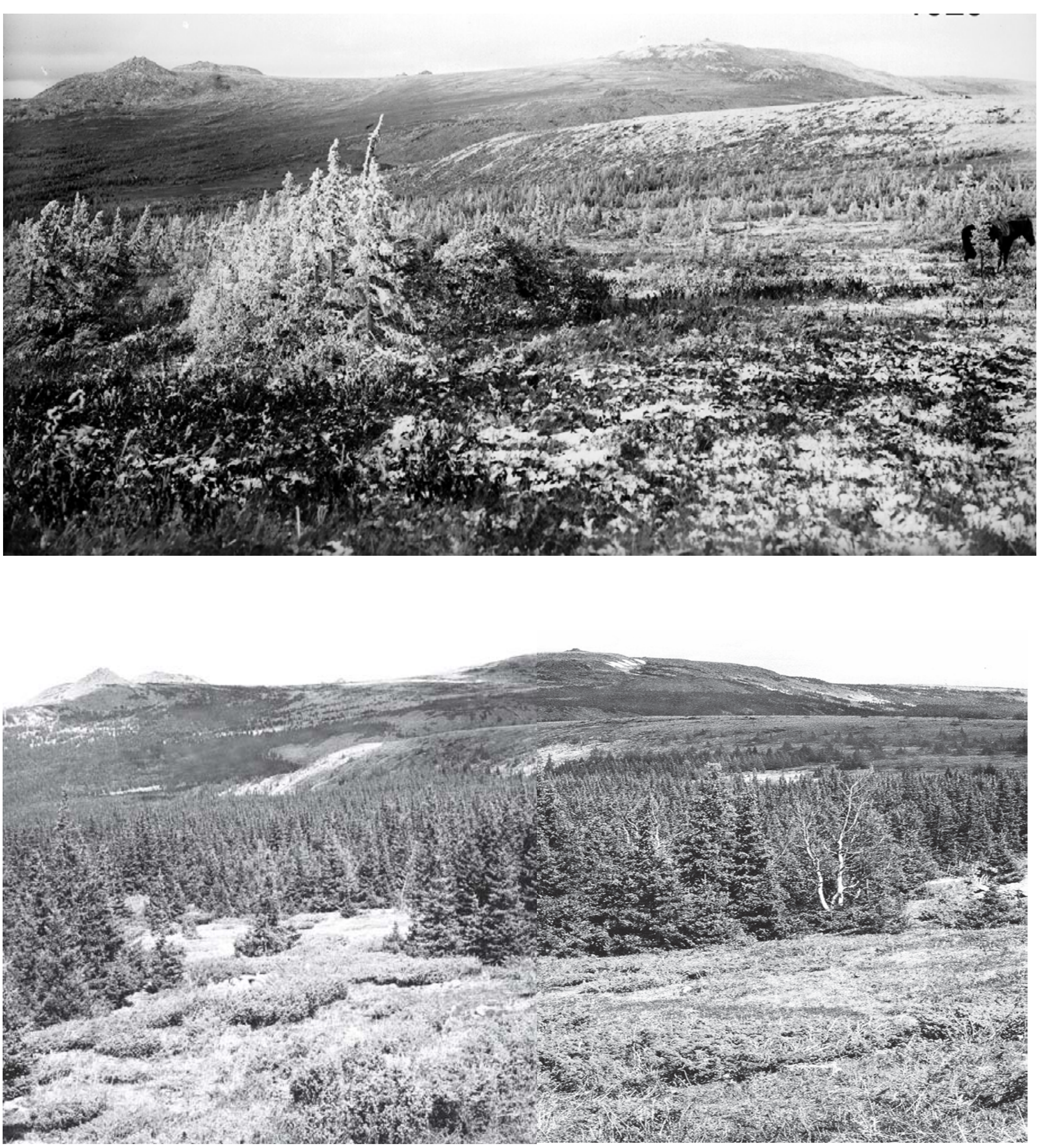

Figure 2. Bolshoi Irmel Mountain in the Southern Urals, showing vegetation thickening and tree-line advancement. Top photo is from 1929, bottom from 1999. Reproduced from PAGES News vol. 11 (1).

After several decades of modelling was available for boreal forests, Soja et al. (2007) examined the impacts that had been predicted and concluded that climate-driven alterations are now noticeable in some regions, involving predicted changes in fire frequency and intensity, increased insect infestations, uphill movement of tree-lines and a decline in growth of Alaskan white spruce *Picea glauca*.

4.3.3. Detailed current observations

Reports from various parts of the world are showing that the effects of climate change are already becoming apparent across a range of ecosystems (Parmesan, 2006; Boisvenue and Running, 2006). It is often difficult however to attribute growth changes definitely to climate changes. Parmesan and Yohe (2003) performed a meta-analysis of range boundaries for 99 flora and fauna species and of phenological changes for 172 species. After examining this data, conclusions made by Parmesan and Galbraith (2004) from the meta-analysis was that boreal plants and North American plants show strong evidence of climate change driven effects at a continental scale, and that tundra plants show such effects at a regional scale.

4.3.3.1. Phenological records and growing season length

Phenological records in some cases go back centuries (Cleland et al., 2007), and can in many cases show a clear correlation with rising temperatures (Menzel et al., 2006). Phenological changes in response to climate variability have been noted in many environments, and provide an easily observable record of biological response to climate variability (Sparks and Menzel, 2002), (Walther, 2003). Most records pertain to agricultural crops, and there is a shortage of records for forest trees (Badeck et al., 2004). Linderholm (2006) published a broad-ranging review of regional and global phenological trends.

The European growing season has lengthened by almost 11 days since 1960 (Menzel, 2000), perhaps as much as 20 days in some areas (Linderholm, 2006; Walther and Linderholm, 2006). The green canopy duration of sugar maples *Acer sachcarum* in North America has increased by ten days since 1957 (Richardson et al., 2006). Phenological changes in Wisconsin suggest an advance of spring by an average of 0.12 days per year (Bradley et al., 1999). Records taken regarding *Ginkgo biliba* trees in Japan suggest a growing season length increase by 12 days since 1953 (Matsumoto et al., 2003). Based on collected phenological data, Chen and Pan (2002) found that the growing season in eastern China extended by 10 days with a one degree rise in late winter and spring air temperatures. Studies across the US corn belt however found no statistically significant changes over the past 90 years (Miller et al., 2005).

Ahas et al. (2002) report that spring advanced four weeks earlier in western Europe from 1951 to 1998, and was retarded two weeks in parts of Eastern Europe. Similarly, a study by Zheng et al. (2006) found advances of 1.1 to 4.3 days per decade in the north of China but a delay of 2.9 to 6.9 days per decade in some other regions. Changes in the flowering-times of several Australian *Eucalyptus* species have been studied, with responses to increased temperature and rainfall either earlier or later, depending on the species (Keatley et al., 2002). Responses for *E. microcarpa* and *E. polyanthemos* to a one degree temperature rise showed earlier flowering by 41 and 43 days, while later flowering was observed in *E. leucoxylon* and *E. microcarpa*.

Remote sensing technology can be used to detect the onset on of spring, with the ‘green wave’ (Schwartz 1998) easily detectable from space. Satellites however detect a composite of vegetation greening, which can be difficult to reliably correlate with individual species’ spring responses (Badeck et al., 2004). Zhou et al. (2001) analysed more sophisticated NVDI (Normalised Difference Vegetative Index) data from 1981 to 1999, and found that over 60% of the vegetated parts of higher-latitude Eurasia showed increasing greenness trends, with a growing season extension of 18 days in Eurasia and 12 days in North America.

4.3.3.2. Vegetation thickening and range changes

Vegetation thickening has been observed in several Australian savannah and semi-arid woodland environments (Hughes, 2003). This has been attributed partly to increased rainfall (Fensham et al., 2005) and CO_2 fertilisation effects (Berry and Roderick, 2006), but the changes to grazing patterns and to traditional aboriginal burning practices is probably the most important factor (Lunt, 2002). Similarly, the expansion of rainforest species into Eucalypt areas and of Eucalypts into grasslands is also often partly a result of changed fire regimes (Fensham and Fairfax, 1996), but climatic changes may also have appreciable effects. Eucalyptus expansion into subalpine grassland may be attributable to recent warming and a reduction in frosts (Wearne and Morgan, 2001).

Broad scale ecosystem changes have been observed in northern Sweden, with changes from birch to pine (Berglund et al., 1996). Advances and thickening of spruce and fir have been noted in the Rocky Mountains of the western USA (Hessl and Baker, 1997), and Caccianiga and Payette (2006) discuss the expansion of white spruce *Picea glauca* in the Hudson Bay area and conclude that warmer climatic periods increase spruce densities but have not resulted in an appreciable latitudinal shift. Walther (2003) reviews several examples from temperate regions.

The northward expansion of lodgepole pine *Pinus contorta* var. *latifolia* in Canada is discussed by Johnstone and Chapin (2003), who find that the species has not expanded to its northward climatic potential. The movement of mountain birch *Betula pubescens* ssp. *tortuosa* into alpine areas of northern Sweden has been studied by Truong et al. (2007), who used genetic methods to demonstrate that the species is currently colonising higher altitudes due to warming temperatures. Alpine tree-line advancement has been also recorded in Sweden by Kullman (2002), in Bulgaria (Meshinev et al., 2000) and in the Ural Mountains (Mazepa, 2005; Kapralov et al., 2006).The study by Mazepa (2005) is built on a long-term polar Ural study established by S.G. Shiyatov in the early 1960s, and shows Siberian larch *Larix sibirica* colonising previously tundra areas over the past 80-90 years. Soja et al. (2007) provide several references for upward tree-line shifts throughout Siberia, and Theurillat and Guisan (2001) for the European Alps. Tree-line movements in the Spanish Pyrenees have been negatively linked to March temperature variability, warming temperatures tending to promote vegetation thickening rather than tree-line advancement (Camarero and Gutierrez 2004).

Increased fire has caused the boreal treeline in eastern Siberia to move southward, involving the conversion of 50 million hectares of forest to treeless vegetation (Vlassova 2002; Callaghan et al. 2002). This 100-250 km wide ‘human induced’ treeless belt between the taiga and tundra increases in size by 0.3 million hectares per year (Shvidenko and Goldammer 2001).

Mangrove forests in Bermuda and Irian Jaya have been found to be retreating as a result of sea level rise (Ellison 2003).

4.3.3.3. Fire frequency and intensity

Savarino and Legrand (1998) show evidence in Greenland ice-cores for periods of increased burning from 1200-1350 AD, 1830-1930 AD and slightly 1500-1600 AD. They link these increases to periods of warmer climate, but, speculatively, the early peak may also be partly attributable to the wide-scale land clearing occurring in Europe at that time (Kempter et al., 1997).

Soja et al. (2007) examined the recent fire regimes in boreal areas, and found in Russia that 7 of the 9 years between 1998 and 2006 could be described as ‘extreme’ fire years, and that the area burned in the 1990's was reported to be 19% greater than the 50 year average. In North America, an increase in the frequency of extreme fire years was also noted.

Brown (2006) studied fire frequencies in the Black Hills of South Dakota and Wyoming, and found that increased fire intensities matched El Nino, cool Atlantic Multidecadal Oscillation and warm Pacific Decadal Oscillation global circulation patterns (commonly associated with drought conditions in the western USA).

Groisman et al. (2007) used four different fire-danger indices (one from the US and three from Russia) to assess the likely change in fire-risk for northern Eurasia. The indices were tested against historical fire data for Ontario, British Columbia and Alaska and were found to closely match observed fire frequencies. Their results show an increasing trend in fire-danger, particularly for areas east of the Ural Mountains.

After examining the fire history of SE Australia over the past 2800 years Mooney and Maltby (2006) described the level of fire history in the last 35 years as 'unprecedented'.

Forest ecosystems do not always regenerate along predictable lines post-fire. Bouchon and Arsenoult (2004) document the failure of post-fire recovery of a boreal floodplain in Quebec, and Griffiths (2001) has described the risk to *Eucalyptus regnans* forests of multiple fires within short time-frames.

4.3.3.4. Increased and novel spreads of insects and pathogens

Insect pests are often controlled by low winter temperatures, limiting the emergence of pest numbers the following spring. Warmer spring and summer temperatures may also hasten insect maturity (Berg et al., 2006). A series of dry warm summers in the late 1990s in Alaska allowed spruce beetle *Dendroctonus rufipennis* life cycles to complete in one rather than 2 years (Soja et al., 2007), and the subsequent explosive beetle outbreak caused 90% tree mortality on Kenai Peninsular in Alaska. Mountain pine beetle *Dendroctonus ponderosae* in western North America is climatically limited, but has recently been spreading northwards and to higher latitudes (Carroll et al., 2004). The recent extreme outbreaks of mountain pine beetle in British Columbia have been linked to warmer climatic conditions (Carroll et al., 2004), as have uncommon outbreaks of the insect pest *Argyresthia retinella* in northwest Norway (Tenow et al., 1999). Diseases are also to a large extent climatically controlled and the rising incidence of Swiss needle cast disease in the Oregon Coastal Ranges has been shown to be positively correlated with mean winter daily temperatures (Manter et al., 2005).

4.3.3.5. Vegetation growth rates

In South American forests increased growth (Phillips et al., 1998), stem turnover and recruitment rates have been noted (Lewis et al. 2004), but the relative impacts of overall climate change and ENSO driven variability are not known. A long term study in southeastern Brazil by Rolim et al. (2005) showed a small reduction in biomass over the years 1978-2000. In alpine and boreal regions, Grace et al. (2002) reviewed evidence of increased tree growth at the upper latitudes and elevations, and decreased growth at the lower edges. Tree ring growth measurements demonstrate increased growth of trees in the arid south-west of the United States (Swetnam and Betancourt, 1998).

Net Primary Production (NPP) of vegetation has increased in some areas, over some timeframes. This has been demonstrated for the United States (Hicke et al 2002), China (Piao et al., 2005), Europe (Schulze et al., 1999) and globally (Nemani et al., 2003; Boisvenue and Running, 2006). Nemani et al. (2003) determined a 6.17% increase in global NPP, and demonstrated that 40% of this could be attributed to climate change. However, Ciais et al. (2005) show a 30% drop in Gross Primary Productivity in 2003 in Europe (possibly due to the heat-wave conditions in that year), and Feeley et al. (2007) show decelerating growth in tropical trees, linked in part to increased annual mean daily minimum temperatures. In Russian Karelia, Voronin et al. (2005) show a decrease in NPP linked to reduced rainfall. Wilmking et al. (2004) examined cores from Alaskan white spruce in two locations and found conflicting growth rates with warmer temperatures, while Barber et al. (2000) found that over the past 90 years growth in white spruce has decreased with rising temperatures.

5. ECONOMIC IMPACTS

5.1. Background

The economic aspects of forests' adaptation to climate change do not seem to be presently receiving a great deal of attention at a policy level. The inherent uncertainty of climate predictions, coupled with the equally uncertain nature of economic predictions, makes meaningful long-term forest economic modelling extremely problematic. Nevertheless, forest managers are accustomed to dealing with timeframes beyond their own lifetimes, and the goal of producing cost-effective raw materials from forests is no different now than at any time in the past. An understanding of what *may* happen to forests, in dollar terms, will be of great benefit to those charged with implementing responsible risk management in the forest industry.

5.2. Dynamic modelling of the US timber market

Most early economic modelling of ecological effects utilised a static approach, where an eventual steady state is assumed at some point in the future. However, climate changes, ecosystem adaptations and market forces are all dynamic systems, and static modelling may not capture the important adjustments in the three systems as they adapt to each other.

Sohngen and Mendelsohn (1999) discussed a methodology for dynamically modelling the effects that large-scale ecosystem effects have on markets. The resource model they created allows for consideration of a resource base of different products (tree species and wood products), growth rates, ages, changes in market demand, harvest cost, regeneration costs, interest rates and the rent cost of holding land. Two more variables are used to control the model; harvest volumes and reinvestment (regeneration) expenses.

In applying this model to the US timber market, Sohngen and Mendelsohn (1999) assume that the object of management is to maximise future income over an infinite time period. As trees follow a concave yield function, this assumption results in an implication that the oldest trees from each species will be harvested first. The issue of commercial or non-commercial thinning is not addressed in the paper, but it may be that this could be modelled as a positive or negative regeneration cost.

Climate effects were then included in the modelling, with changes considered to growth rates due to CO_2 fertilisation affects (with differing effects on trees of different ages) and projected tree mortality rates of particular species. Faster growth rates imply a greater mean annual increment, which may serve to either decrease or increase optimal rotation times, depending on the other variables in the model. Mortality rates may increase harvest volumes in some periods through salvage logging, but also increase waiting costs of delaying harvests, and thus may act to reduce the rotation times of stocks vulnerable to dieback.

Sohngen and Mendelsohn (1999) assume a doubling of CO_2 levels to 660ppm by 2060, using two general circulation models, from the United Kingdom Meteorological Office (UKMO) and Oregon State University (OSU). These two commonly used climate models are used to represent alternative extremes of expected climate change for commonly used Global Circulation

Models (GCMs). Changes in weather variability and extreme events are not considered in the Sohngen and Mendelsohn (1999)'s modelling.

Biogeographical and biochemical responses to climate changes are based on the three models of each type as used by VEMAP Members (1995). This approach is designed to reflect the lack of certainty in vegetation modelling, and show the range of possible results that may occur. Sohngen and Mendelsohn (1999) simplify VEMAP Members (1995)'s vegetation classes into four timber species: loblolly pine, Douglas fir, white pine and ponderosa pine. Model outputs are harvest volumes, timber prices and regeneration proportions of each species.

Management intensity is also an important factor considered in the modelling. High intensity landholders may be presumed to follow economically rational decision paths, based on the obligation to maximise profits over an infinite time period. This often includes the need for higher regeneration expenditure. Low intensity managers however often only harvest at times of high immediate return, and regenerate lands naturally. Sohngen and Mendelsohn (1999) assume that high-value forest land will be managed with high intensity, and vice-versa.

The model is run separately for two possible ecological forest-response scenarios, dieback and regeneration. The dieback scenario assumes that tree mortality will be significant, and management responses will be proactive (salvage logging) and aimed at maintaining long-term productivity. This has the effect of hastening species change, and improves economic outcomes (Winnett, 1998). The regeneration scenario assumes that stands are harvested normally and only natural regeneration will occur. The combination of these with the climate, biogeographical and biochemical models used provided Sohngen and Mendelsohn (1999) with 36 possible future scenarios. All of these scenarios indicated an eventual increase in timber supply to 2145 (~20 billion 1982 US dollars) from the continental United States, largely due to the expected range expansion of the highly productive loblolly pine species.

5.3. Regional Studies

Regional economic studies (with various methodologies) have been published for North America (Irland et al., 2001; Sohngen and Sedjo, 2005), the continental United States (Joyce et al., 1995; Sohngen and Mendelsohn, 1999; McCarl et al., 2000), Canada (van Kooten, 1995), Brazil (Fearnside, 1999), Australia (in Kirschbaum, 2004), the Czech Republic (Šišák and Pulkrab, 2002), US Southern States (Burton et al., 1997; de Steiguer and McNulty, 1998), US Mid Atlantic region (Rose et al., 2000), Oregon State (CLIISE, 2007) and Saskatchewan State (Hauer et al., 2004). Sohngen et al. (2001) point out however that regional studies often do not take the greater global economic perspective into account, and thus may fail to adequately reflect the climate change driven changes in the commercial advantages/disadvantages of their region. A recent review was provided by Sohngen et al. (2007).

5.4. Global Studies

5.4.1. Sohngen et al. (2001)

Sohngen et al. (2001) applied the modelling approach of Sohngen and Mendelsohn (1999) to global forests using the BIOME3 ecological model (Haxeltine and Prentice, 1996), and two climate models: Hamburg T-106 (Claussen, 1996) and University of Illinois at Urbana-Champaign (UIUC; Schlesinger et al., 1997). To take current non-forest land use into account, Sohngen et al. (2001) do not allow the spread of forests into prime agricultural land (as defined by Olson et al. (1983)).

When the model is run to simulate baseline (no climate change) conditions, production growth is predicted for subtropical regions of Africa, Oceania, Asia Pacific and South America, due to the relatively low cost of establishing eucalyptus species, radiata and other southern US pine species in plantations. Without climate change, subtropical plantation areas are expected to increase by an average of 273000 hectares per year, with 20 to 27 percent each in South America, Africa and Oceania. This figure does not include fuelwood plantations.

BIOME3 predicts higher net primary productivity, increasing forest areas and large-scale forest-type conversions. Both forest losses and gains (in different areas) are predicted under both climate models, with a net gain of 27% of area and 38% of productivity under the Hamburg scenario and 19% of area and 29% of productivity under UIUC. In Europe, 78% of the gains in forest area are predicted to be in the Mediterranean region, which raises the question of how effectively increased fire intensity has been considered by BIOME3 and Sohngen et al. (2001). The main region to benefit from expected forest-area increases are the steppelands of Belarus, southern Russia, Kazakhstan and Uzbekistan, to the tune of 26-28 million hectares of productive temperate softwoods and hardwoods.

Timber prices are expected to decline under all scenarios. BIOME3 predicts high levels of near term (1995-2045) dieback, particularly in mid-high latitude regions of Oceania, China, Russia and North America. In the longer term, tree species in these areas are replaced with more productive species, and productivity rises. Without considering dieback (the regeneration scenario) species are still expected to change toward a more productive forest type, but the productivity gain takes longer to develop .Long term timber prices under all climate changes converge, to a point approximately 20% lower than the no-climate change baseline by 2140.

Figure 3 shows the mean projected dieback, the net forest area change, expected increase in NPP and expected yield increases by 2145. It can be seen that in tropical areas yield increases closely match NPP increases, but in North America and Oceania there is a wide difference. This highlights the importance of ecological and management responses to the expected high levels of dieback in these regions.

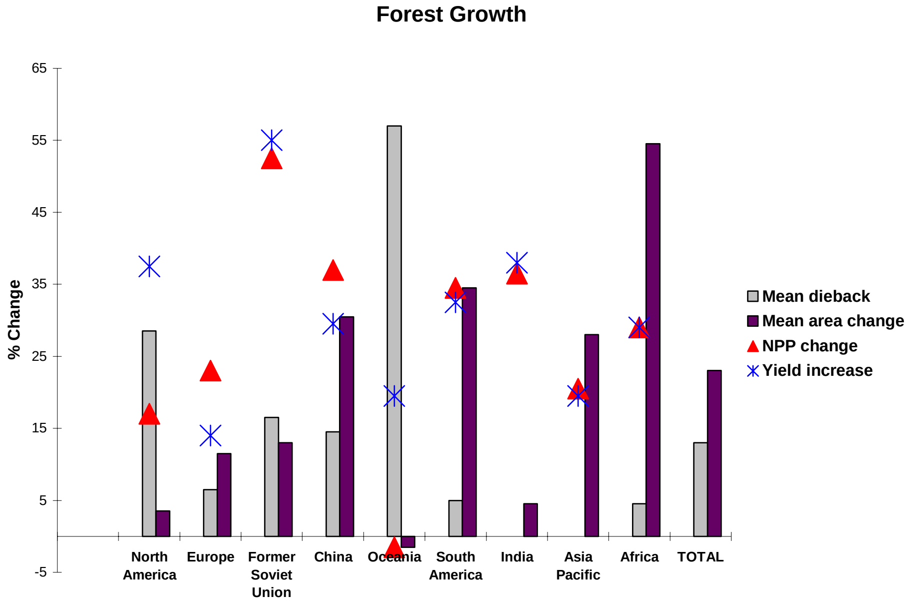

Figure 3. Forest area change, dieback, NPP change and yield increases to 2145. Produced from data in Sohngen et al. (2001).

Figure 4 shows regional projected timber production over the 2 fifty year periods between 1995 and 2145. Under the UIUC model, most areas increase production by somewhere around the global average, give or take ten percent. The standout exceptions to this are the Former Soviet Union countries, with a large increase in production after 2045. The relatively benign Hamburg model however gives a large early production increase to low-latitude areas (notably India and South America). This is due to the ability of producers in those countries to adapt quickly to climate change, through the use of fast-growing plantations. A late increase occurs in the FSU and China, as native species in the main production regions in those areas are slower growing, and hence there is less opportunity for adaptive management. Under this scenario, Oceania shows a consistent slow fall in production.

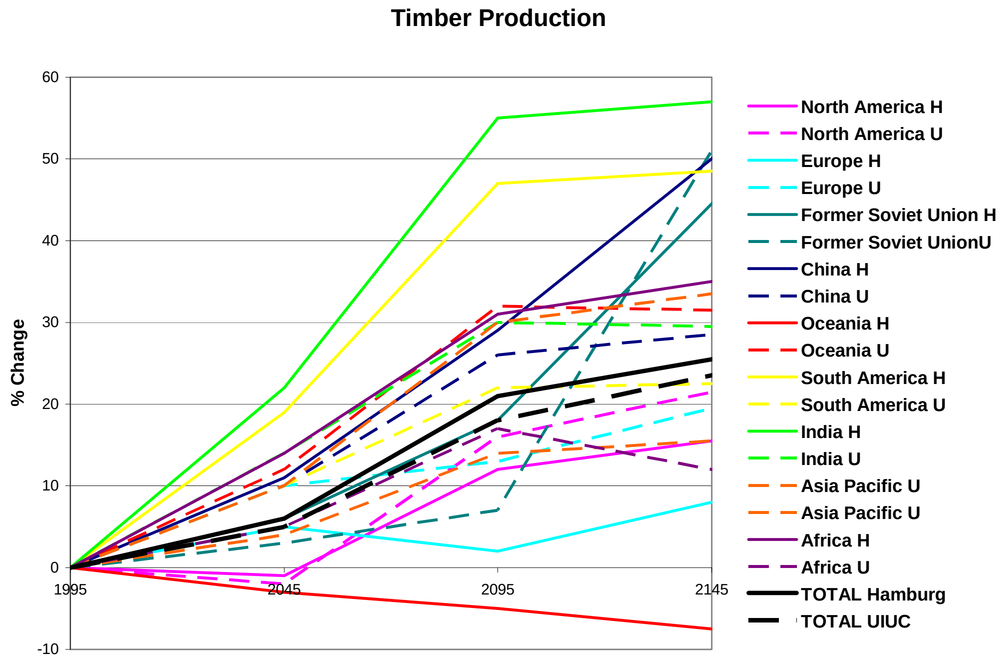

Figure 4. Regional timber production trends to 2145. Produced from data in Sohngen et al. (2001).

Sohngen et al. (2001) also present a table showing the regional welfare effects to 2145 under both the Hamburg T-106 and UIUC models, each for the dieback and regeneration scenarios. Figure 5 displays the results from the mean figures across the four scenarios for each region. Consumer surplus refers to the expected benefit to consumers through lower prices, while producer surplus effectively means increased profits for producers due to climate change. Net surplus is thus the expected gain to the regional economy resulting from climate change effects on forests.

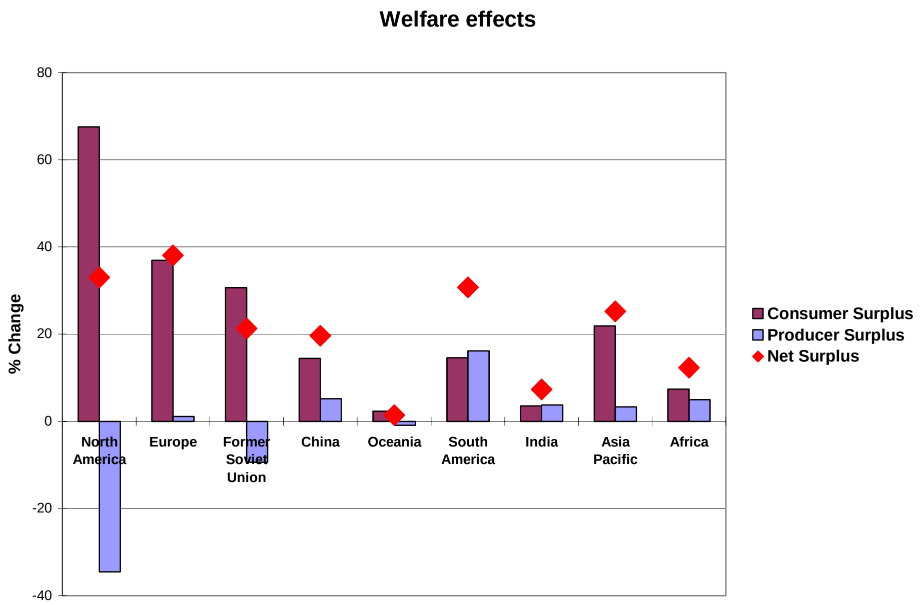

Figure 5. Welfare effects of increased forest productivity. Produced from data in Sohngen et al. (2001).

Under all scenarios examined by Sohngen et al. (2001), consumers in all regions are expected to benefit from the expected increased production rates. Projected lower timber prices are expected to impact most severely on producers in the higher latitudes, negating their gains from higher productivity. Sub-tropical producers however are expected to enjoy increased surpluses due to climate change in all scenarios except for the UIUC regeneration scenario, where Asian Pacific and African producers may experience a negative surplus.

The shift in comparative profitability of the wood-products industry from the high latitudes to the sub-tropics has been mooted in several reports (Poschen and Lövgren, 2001; Bael and Sedjo, 2006; Easterling et al., 2007), and this is supported by Sohngen et al.'s modelling. This effect has already been noted in Australia, where the Federal government provides tax incentives for plantation establishment to reduce the reliance on (predominantly higher-latitude) native forests, but regional governments in southern areas are imposing additional costs of up to $AUD1800 per hectare on new plantations in response to recent drought conditions (Rod Meynink, pers. comm., October 2007). Plantation companies in Australia are now increasingly developing areas in the subtropical north.

5.4.2. Perez-Garcia et al. (2002)

Perez-Garcia et al. (2002) also conducted a global forest economic modelling exercise, using three climate scenarios projected by the Integrated Global System Model (IGSM, see Prinn et al. 1999), vegetation modelling with the Terrestrial Ecosystem Model (TEM, Xiao et al. 1998) and two scenarios of economic modelling using the CINTRAFOR Global Trade Model (CGTM, see Cardellichio et al. 1989). No attempt was made at modelling the change of vegetation species, only the biological and economic responses of existing timber stocks.

Results in Perez-Garcia et al. (2002) are presented as changes in global vegetative carbon in 2040 as compared to 1985, aggregated welfare change for the major timber sectors under both extensive (harvest volumes not constrained by infrastructure or political factors) and intensive margins (Perez-Garcia et al. 1997) and a more indepth analysis of sawlog prices, harvest volume changes and economic welfare changes for a range of national economies. Average global welfare changes show a 2.07% increase in consumer surplus and a 2.12% increase in producer surplus, but there is wide variability in regional results. Results for the extensive scenario show a greater proportion of the surplus going to consumers (due partly to increased harvests in the FSU and Eastern Europe) but the overall surplus is similar in both scenarios.

Perez-Garcia et al. (2002) also present an analysis of projected changes in global growing stock of both softwood and hardwood species, each for the three climate scenarios. Upper and lower bounds are shown, reflecting the uncertainty in the economic responses of non-market economies. Figure 6 shows the overall aggregated results for all scenarios, assuming a 70/30 split between softwood and hardwood on global timber stocks. The slope of the timber production increase presented by Sohngen et al. (2001) is shown for comparison.

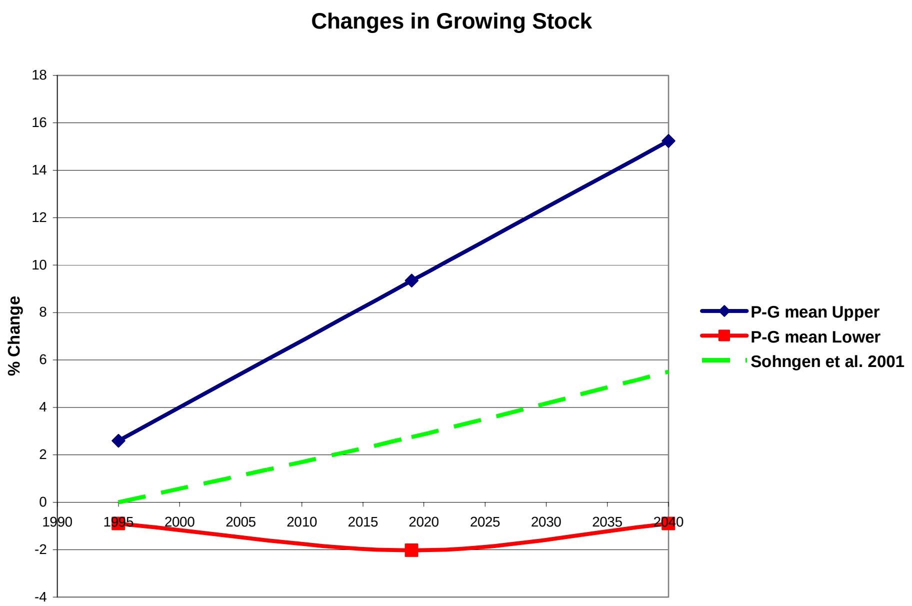

Figure 6. Changes in forest growing stock to 2040. Produced from data in Sohngen et al. (2001) and Perez-Garcia et al. (2002).

Although the comparison of disparate studies in this manner is not strictly rigorous, it does suggest that the uncertainties inherent in forecasting the economic effects of climate change on forests may be manageable.

5.4.3. Lee and Lyon 2004

A third independent study was carried out at roughly the same time as the preceding two. Lee and Lyon (2004) modelled the global timber market using BIOME3, the Hamburg climate model and a version of the Timber Supply Model (TSM; Sedjo and Lyon, 1990) that they adapted to include global climate-change driven ecosystem adjustments. In their adjustments they include consideration of the former Soviet Union as part of the market-driven global economy, an increase in plantation areas of 2.8 million hectares per year in developing regions and an increase in native forest conservation areas. Their modelling includes both dieback and regeneration, in ratios calculated from the output of the BIOME3 vegetation model. Three demand scenarios are presented: normal, high and very high.

Lee and Lyon (2004)'s results for normal timber demand show a global increase in total production volume of approximately 65% from 1995 to 2085, with the US South and Eastern Siberia the dominating areas both in real terms and as the regions with the greatest increases in production. Their base scenario (without climate change) shows a growth of 31% over this period. Welfare benefits range from 4.76% under normal demand, to 17.07% under very high demand.

5.5. Market-driven adaptation

Sohngen and Mendelsohn (1999) also stress that the market has the opportunity to ease the adaptation of forests to climate change, through the planting or assisted regeneration of species better suited to future climate possibilities. Those species that are best adapted to changed climate conditions will also have a commercial competitive advantage, and hence the use of economic modelling can also provide management advice suitable for both commercial and ecological benefit. Irland et al. (2001, p. 754) make a key point in reference to the economic aspects of the adaptations of forests to climate change: "*Adaptation in…timber and wood product markets will offset some of the potential negative effects of climate change*."

6. SOCIAL IMPACTS

6.1. Introduction

Past climate changes have had cataclysmic effects on human societies (Fagan, 2000), and Stern (2007, p.84) has concluded that "*Climate change will have increasingly severe impacts on people around the world, with a growing risk of abrupt and large-scale changes at higher temperatures.*" Particularly in developing areas, high percentages of the population are directly dependant on forests and so any changes to the forest could significantly affect their livelihood (Gunwan et al., 2004; Mamo et al., 2007).

Sociological literature abounds with conflicting terminology and paradigms (Eakin and Luers, 2006; Vogel et al., 2007), sometimes within the one document (see Adger et al. (2004) for a discussion of IPCC (2001)). This review will present definitions drawn or adapted from existing literature that are best suited to discussing the social aspects of the adaptations of forests to climate change.

6.2. Dependency, Vulnerability, Risk and Adaptation

The concept of 'dependency' can be difficult to precisely define (Stedman et al., 2007), as it can be extended beyond traditional views of subsistence or economic dependency (with various definitions) to also encompass broader themes of well-being (Haynes 2003; Daniels 2004; Kennealy et al., 2006), personal and community identity (Carroll, 1995), sense of place (Beckley et al., 2004) or ecosystem services (Daily et al., 1997; FAO, 2005b). Byron and Arnold (1999) examine forest dependence from three perspectives: forest dwellers, adjacent farmers and commercial users. Stedman et al. (2007) found wide variations of purely economic dependency across communities, depending on whether the study methodology revolved around employment or income, or related to base employment (or income) in the forest sector, or proportional to employment or income across all sectors. Beckley (1998) discussed the varying types of dependency prevalent at different spatial scales, and in different types of community (Beckley, 2000). McDonough and Parker (1995) enunciated the views of 'direct' and 'indirect' dependence, and Daniels (2004) related dependency simply to the area of forest associated with a community. This review will adapt the definition of 'rural resource community' given by Thellbro (2006, p. 14), and define a 'forest resource-dependent community' as "*A human society that reside in a comparatively small geographic area in which people rely on the extraction and/or processing of forest-products for their livelihoods*". Although the *importance* of non-economic factors in these communities is recognised, those factors do not *define* the community in the same way that resource usage does, and broadening the definition to include tourism, aesthetics, ecosystem services etc. risks defining *all* society as forest dependant. This may be true, but is useless for defining particular communities.

Resource dependency has been associated with poverty in both Western communities (Kennealy et al., 2006) and developing countries (Sunderlin et al., 2004). The lack of diversity inherent in relying on one particular resource makes communities vulnerable to impacts on their resource base. Forest resource dependency in postcommunist countries has been studied by Staddon (2001), Moran (2001) and Metzo (2001).

Because of the uncertainty in climate change modelling the particular physical hazards that may impact on particular communities cannot be precisely predicted. The focus of researchers in this field has thus moved away from an 'impacts' approach to concentrate instead on the vulnerability of communities to adverse climate change effects (Adger et al., 2004). Socio-economic vulnerability is described by the IPCC (2001, p. 6) as "*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.*" This definition relates to biophysical vulnerability (risk) but is not so well suited to sociological studies (Adger et al., 2004; Straussfogel, 2006). Social vulnerability may be viewed as a part of the sensitivity of biophysical vulnerability, in that social vulnerability is not in itself directly affected by climate change, but the total effect on the community due to its biophysical vulnerability will be reduced or amplified according to its social vulnerability. Effects on the community may well then flow through to affect social vulnerability.

Social vulnerability is inversely related to the concepts of community resilience and community capacity, which are increased through greater economic diversity and lower dependence on the timber industry, and through increased community autonomy and local leadership (Parkins and MacKendrick, 2007). Daniels (2004) defined 'socioeconomic resilience' as "*…the ability of a community to adapt to change.*", and developed a 'sustainability index' to rate communities' level of vulnerability to forest management changes, including indices for lifestyle diversity (mobility, ethnicity, urbanness, race, income and education), economic diversity (employment across a variety of industries) and population density. Kelly and Adger (2000, p. 328) defined social vulnerability in terms of community capacity: "*…the ability or inability of individuals and social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being*", and from a case study of cyclone impacts in Viet Nam identified three 'vulnerability indicators': poverty, inequality and institutional adaptation. 'Community capacity' in Parkins and MacKendrick (2007) related to indices for human economic hardship, crime, health, education, children at risk and youth at risk.

The concept of 'risk' was studied by Sarewitz et al. (2003), who divided risk into 'event risk' and 'outcome risk'. Event risk is defined as the "*risk of occurrence of any particular hazard or extreme event*", while outcome risk is "*the risk of a particular outcome*" and vulnerability is the "*inherent characteristics of a system that create the potential for harm but are independent of the…event risk*" (Sarewitz et al., 2003, p. 805). 'Vulnerability' in this case could be considered as social vulnerability, and hence outcome risk is effectively equivalent to biophysical vulnerability (Adger et al., 2004).

Risk perception has also been identified as an important element in reducing vulnerability. Davidson et al. (2003) examined the climate change vulnerability of Canadian communities, and included community capacity (in particular, the constraints on adaptability, attitudes to causal factors and the nature of forest industry decision making), exposure (objective risk assessment) and community risk perception. Parkins and MacKendrick (2007) also gave a great deal of attention to community perceptions regarding the Mountain Forest Beetle impacts in British Columbia; in terms of perceptions of the degree and nature of the physical risk, the perceived risk to the community, the satisfaction with local management efforts and the level of trust in government agencies. They argue that heightened community awareness and perceptions of risk raise a community's adaptive capacity, and thus lower vulnerability. 'Vulnerability' in Parkins and MacKendrick (2007) has physical, social, political and economic elements.

Adaptive capacity may be broadly defined as "*…the ability of a system to adjust to, or cope with, stress.*" (Parkins and MacKendrick, 2007). Specifically in relation to climate change, the IPCC (2001) uses the definition "*the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.*" In the social sciences, Straussfogel (2006) offers "*Adaptive capacity is the ability of a social system to change or cope with stress or anticipated stress*". The inclusion of 'anticipated stress' is mirrored in IPCC (2001)'s definition of 'adaptation': "*Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*". An adaptation in a social science sense then is an activity that raises adaptive capacity and reduces social vulnerability, which reduces the sensitivity of the system and hence reduces the biophysical vulnerability, or overall outcome risk.

Tschakert (2007) has pointed out that most adaptation strategies developed for sub-Saharan Africa rely on physical adaptation, and little attention is given to strengthening the adaptive capacity of the communities at risk. The terminological distinctions made by Adger et al. (2004) are important, because they point out that actions to reduce the potential damage to society from climate change may be directed at either the biophysical realm or the social realm, and give a framework in which to assess risks and assign priorities.

6.3. Impacts and Risks

Social impacts resulting from forest's adaptation to climate change may be viewed from four perspectives: the impacts on communities that depend on commercial forestry, the impacts on communities that depend on forests wholly or partly for subsistence living, health and ecosystem services and recreational and lifestyle issues.

6.3.1. Commercial forestry dependency

Communities that depend on commercial forest range from those with a reliance on high-tech industrial methods such as the United States to Central African nations still with a high level of labour intensive, non-industrial forestry operations (Forests Monitor, 2007). Although Sohngen et al. (2001) modelled an overall increase in welfare for forest producers worldwide, they point out that this is not expected to be consistent, and some areas will suffer. The societies in these areas then could be expected to come under pressure from job losses and a reduction in community viability. Davidson et al. (2003) note that forest-based communities will be particularly vulnerable to the effects of climate change, both from the direct effects on their resource base and because of the social contexts of those communities.

The physical risks (discussed in section 4 of this paper) may relate to reduced forest outputs, increased fire risk, pest outbreaks (Williams and Liebhold, 2002), drought, windthrow damage, ice storms (Irland, 2000) or weed invasion. Secondary effects such as a reduction in land price or uncertain land tenure may add to the pressure on communities (FAO 2005b). These are all things that forest resource dependent communities are accustomed to dealing with, but increased intensity will stress communities further, particularly if multiple stressors are applied simultaneously (Davidson et al., 2003). Flint (2006) noted that impacts community attitudes to the spruce beetle outbreaks in Alaska in the 1990s varied, with short-term gains available for some from increased timber salvage harvesting but reductions in quality of life for others.

The success of communities in addressing these challenges will depend on their adaptive capacity. Williamson et al. (2007) list several important factors in assessing a community's adaptive capacity: wealth, mobility, education, social networks, trust, institutions, risk perceptions, and natural resource endowments. These factors are closely connected to the social indicators studied by many researchers in the context of exploring community sustainability, including Beckley (2000), Berch et al. (2003), Daniels (2004), World Bank (2006) and Parkins and White (2007).

6.3.2. Subsistence dependency

The forest dwellers and adjacent farmers identified by Byron and Arnold (1999) are particularly at risk from climate change. It has been noted that poor regions in general are more vulnerable (Smit and Pilisofova, 2001; KD Singh, 2003) and the link between forest resource dependency and poverty is well established (Oksanen et al., 2003; Sunderlin et al., 2003; Gilmour et al., 2004). Bhatt (2003) has demonstrated how forest degradation has increased unemployment and poverty in India. Nevertheless, the importance of forests in alleviating poverty is also well accepted (Grosnow, 2003; Sunderlin et al. 2005; Innes and Hickey, 2006) and forests have been expressly linked to achievement of the United Nations' Millennium Development Goals (FAO, 2005b; UN Millennium Project, 2005).

Forest dwelling communities (including swidden farmers, see Russell (1988)) with no other source of sustenance could be expected to be impacted very heavily by significant climate change, but little research appears to have been done in this area. Garcia-Barrios and Gonzales-Espinosa (2004) have suggested that a change in forest dominance from oak to pine may reduce yields from shifting agriculture in Mexico. More often a mix of subsistence agriculture and adjacent forest resource use is found. These circumstances have been recently documented for communities in Bhutan (Tshering, 2003), Vietnam (Trieu, 2003), India (Sharma, 2003; R. Singh, 2003), China (Shougong et al., 2003), Malawi (Fisher 2004), Mozambique (Lynam et al., 2004), Ethiopia (Mamo et al., 2007) and West Java (Gunwan et al., 2004). In many cases, the forest is vital for supplies of fuelwood (FAO, 2005a) and non-wood forest products (Rawat and Uniyal, 2003).

The physical risks facing subsistence communities are the same as those in other forest areas, but the lack of support infrastructure and effective political processes increases vulnerability (Adger, 1999; Adger et al., 2003; Brockington, 2007). Poorly designed adaptation programmes (Tschakert, 2007) can negatively impact on subsistence communities. Halsnaes and Verhagen (2007) stress the need for a more holistic approach, with climate mitigation and adaptations strategies tied more closely to community development goals (see also TROFCCA, 2005). A focus on conservation of ecosystems can limit access to resources, and the conflicts between conservation or climate change mitigation goals and the needs of communities has been explained by Colchester (1996), Fearnside (2001), Forest Peoples Project (2007), Tacconi (2007) and Boedhihartono et al. (2007). However, Tilahun (2007) does present one example of how closing forest areas can lead to better economic outcomes for poor communities in Ethiopia.

Tschakert (2007) studied climate change impacts on African Sahel communities and argued strongly for an increase in the adaptive capacity of societies, rather than focussing solely on technical adaptation programmes. Socioeconomic circumstances have a strong bearing on adaptive capacity, and community surveys conducted by Tschakert (2007) identified health, poverty, the threat of hunger, unemployment and poor infrastructure as the leading detrimental issues (Figure 7).

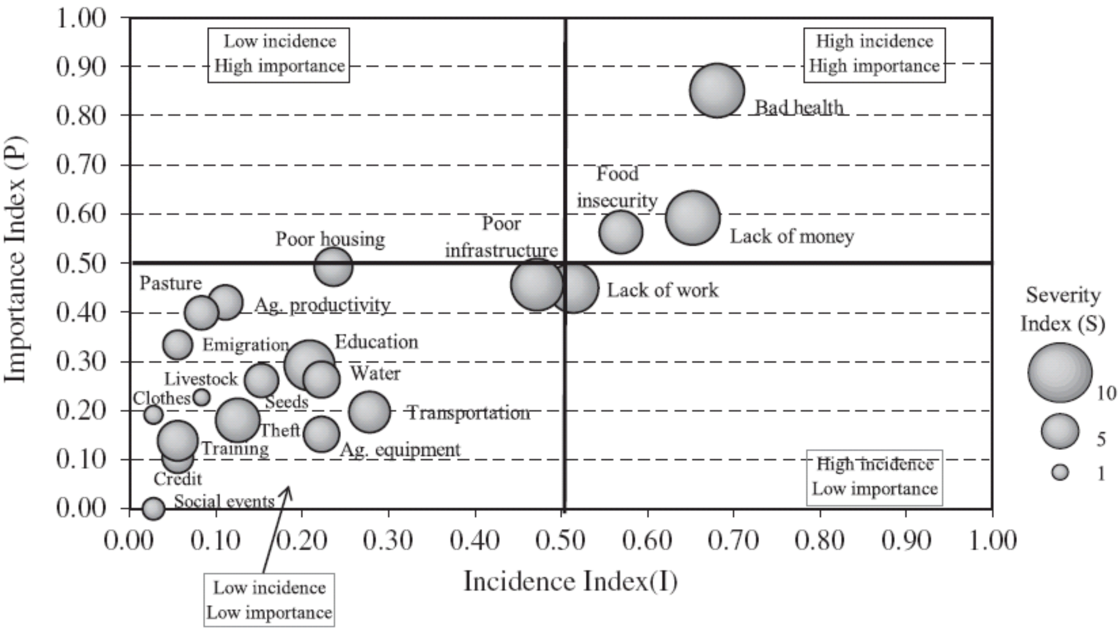

Figure 7. Documentation of significance of stress conditions at the individual, household, and community level for 2005; combined results for men and women. The severity index ranges from 1 (barely noticeable) to 10 (life threatening). Reproduced from Tschakert (2007)

Similarly to studies in commercial forest resource dependent communities, Tschakert (2007) places high value on community risk perception in enhancing adaptive capacity. Surveys of villagers in the African Sahel examined what stresses the community thought important and their understanding of climate characteristics and the causes of climate change. Further surveys included responses from experts from district councils regarding the impacts of climate change, both negative and positive. Figures 8 and 9 (reproduced from Tschakert 2007) show a concept map of each case. It is interesting to note in the figures 2 and 3 how few conceptions were held in common by both experts and villagers, although both groups agreed that climate change may be positive in regard to opportunities for alternative income generation and a lessening of field labour, and negative in respect to the availability of natural resources.

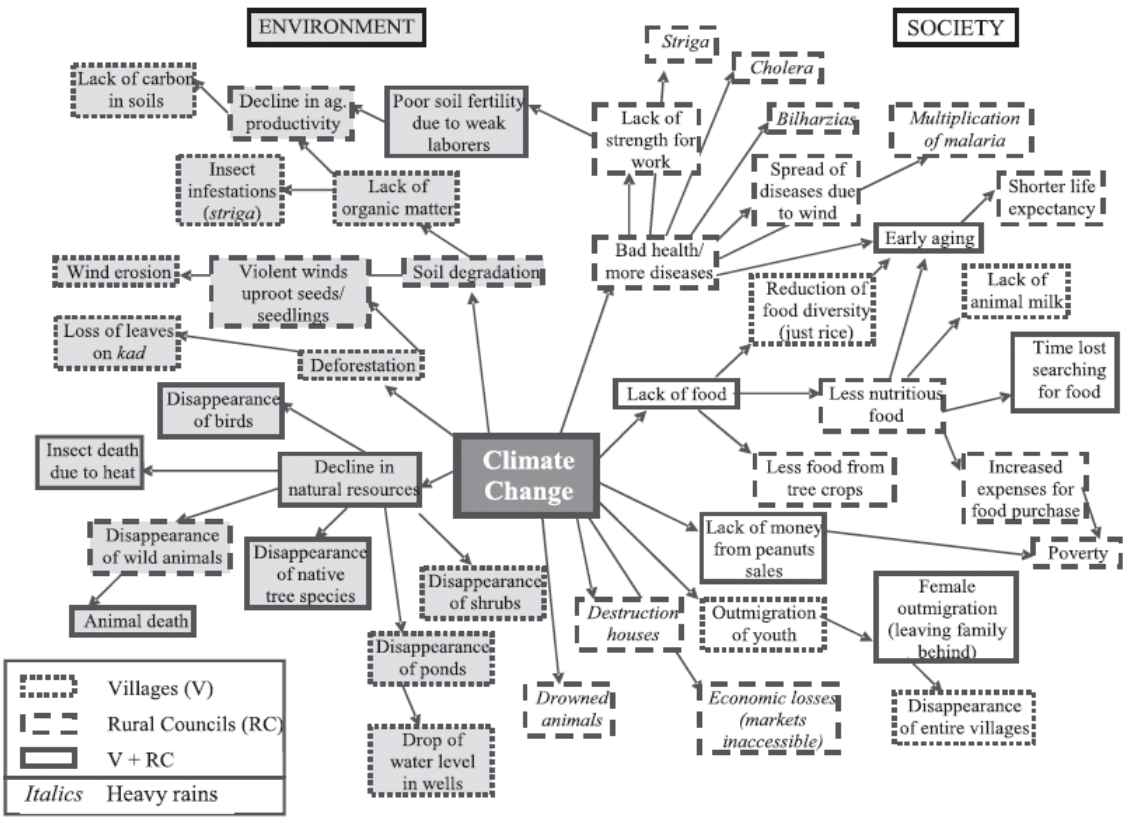

Figure 8. Composite 'expert' and 'non-expert' concept map on negative impacts of climate change. Reproduced from Tschakert (2007)

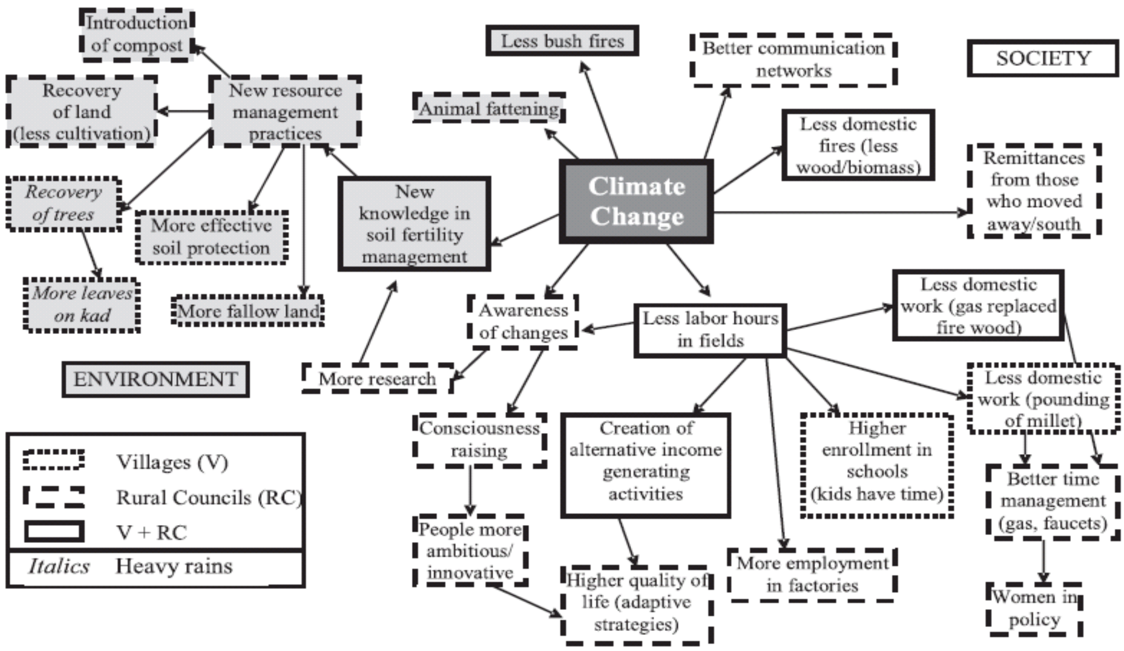

Figure 9. Composite 'expert' and 'non-expert' concept map on positive impacts of climate change. Reproduced from Tschakert (2007)

Forest resource dependent communities in the post-Soviet transition economies are often already under a high degree of economic stress (Moran, 2001; Metzo, 2001). Poor infrastructure in Siberia limits logging (Moran, 2001), and the tourist industry in parts of Bulgaria are likewise hampered by poor access (Staddon, 2001). Industrial forestry in many areas coexists with traditional community forest usage (firewood, forage, mushrooms, herbs etc). Illegal logging is common (Staddon, 2001; Metzo, 2001). The decline of the Russian forest industry in the early 1990s led to economic hardship (Moran, 2001), raising the subsistence dependence on forests of many communities. Rural inhabitants often hunt, fish and gather fruits and berries. A further type of dependence is seen in rural Russian districts such as the north of the Perm oblast, where forest workers (sometimes paid in beans or flour) are responsible for road upkeep and often provide transport services in logging vehicles (Moran, 2001).

Climate change may add to the stresses in these communities, or conversely, the habits of resourcefulness, traditional knowledge and societal structures developed may serve to increase community resilience. This point was also raised in other contexts by Few (2003) and Thomas and Twyman (2005). Staddon (2001, p. 525) quotes a popular Bulgarian folk adage: "*The forests help Bulgarians in hard times*".

6.3.3. Health and Ecosystem services.

The importance of forests to human health and ecosystem services was stressed in the Millennium Ecosystem Assessment (MEA, 2005), but literature that definitely links health concerns directly to the adaptations of forests to climate change does not appear to be available. Some inferences and predictions could however be made from the work of Few (2007) on the health aspects of natural climate disasters, or the discussions of Molyneux (2003) on how a lower biodiversity leads to an increase in the 'generalist' vectors commonly associated with diseases. Secondary effects flowing from an increase in fire affected areas (Salafsky 1994) may include cardio-respiratory problems (Mott et al., 2005) and an increase in mercury levels in fish (Kelly et al., 2006). A change in forest ecosystems may also result in a spread of insect vectors responsible for Lyme disease (Ogden et al., 2006).

Ecosystem services may be adversely affected in some areas, particularly in relation to potable water supplies (Gleik 2000). Daily et al. (1997) listed the following as important ecosystem services:

- Purification of air and water,
- Mitigation of droughts and floods,
- Generation and preservation of soils and renewal of their fertility,
- Detoxification and decomposition of wastes,
- Pollination of crops and natural vegetation,
- Dispersal of seeds,
- Cycling and movement of nutrients,
- Control of the vast majority of potential agricultural pests,
- Maintenance of biodiversity,
- Protection of coastal shores from erosion by waves,
- Protection from the sun's harmful ultraviolet rays,
- Partial stabilization of climate,

. Moderation of weather extremes and their impacts, and
. Provision of aesthetic beauty and intellectual stimulation that lift the human spirit.

6.3.4. Recreational and lifestyle

Recreation is an increasingly important aspect of forest usage, with recreational pressures of various forms on US public lands expected to increase from 21% (off-road driving) to 259% (downhill skiing) over 1987 levels by 2040 (Cornell et al., 1990). Irland et al. (2001) examined the possible climate change effects in fishing, boating, skiing and aesthetics in US forests, and concluded that the impacts were uncertain. Loomis and Crespi (1999) suggested that watersports would rise in popularity, but skiing and forest-based recreation would fall. Warmer temperatures expected to increase mountain tourism in the Rocky Mountains (Richardson and Loomis, n.d.). Wall (1998) points out that the length of the season is crucial for tourist operators.

Lifestyle usage of forests may also be affected. Low density residential use covers 25% of the US (Cirmount Committee, 2006), and the social importance of traditional forest pursuits in Sweden has been pointed out by Thellmo (2006).

7. TRADITIONAL FOREST KNOWLEDGE

7.1. Responses to Climate Variability

Traditional people in many regions have faced climate variability for millennia, and lessons may be learnt from this experience that may be relevant to developing adaptation strategies for climate change. Nyong et al. (2007) describe the example of the African Sahel, where farmers and herders have developed ways of dealing with the recurrent droughts that affect the area. These responses involve weather prediction techniques, soil management and fallow farming, agroforestry and the management of forest reserves. Pastoralists change from cattle to sheep in drier conditions, and move their grazing ranges as required to follow belts of adequate livestock feed.

Fagan (2000) gives several examples of ancient societies' response to climate variability. Sedentary agriculture in the Euphrates valley and Southwest Asia developed partly in response to the Younger Dryas drought conditions of 11000 years ago, and the colonisation of Europe (involving slash and burn agricultural methods) may have been driven by Mediterranean sea-level rise and the flooding of the Black Sea around 5500BC.

Drought in Egypt around 2180BC has been linked to the devolution of power from the Pharaohs to the regional nomachs and the collapse of the Old Kingdom. In contrast, the Egyptian Middle Kingdom (from 2046BC) was able to survive poor climatic periods through strong central administration supported by the populace (Fagan, 2000). Fagan (2000) has also linked poor governance of the Moche civilisation of Peru (100AD-800AD) and the Mayans of the Yucatan peninsular (-900AD) to their inability to successfully respond to El Nino climate variability.

In many cases, the response of indigenous peoples to climate change has been to move. The Anasazi people of what is now the United States' Southwest built a flourishing agricultural civilisation a thousand years ago, but dispersed in response to intensifying drought cycles between 1130AD and 1299 AD (Fagan, 2000). Nyong et al. (2007) mentions the suitability of traditional nomadic pastoralism to variable climates in the African Sahel. The relatively late movement of Australian aboriginals into the North Queensland rainforest may have been due to climate variability (Cosgrove et al., 2007), and necessitated the use of new techniques to make toxic nut crops edible.

Societal customs have been developed as a coping mechanism in many harsh regions. Fagan (2000) discusses the !Kung people of the African Kalahari, who have a sophisticated system of family obligation and mutual reciprocity whereby communities in drought stricken areas can disperse to other communities for the duration of the crisis.

7.2. Knowledge sources

Synergies have been noted between conservation and traditional knowledge (Becker and Ghimire, 2003; Schwartzman and Zimmerman, 2005) that serve the goals of both indigenous people and conservationists. Although commonly indigenous people have a degree of harmony with and understanding of their environment, this is not always the case. Ratsifandrihamanana et al. (2006) mention cases from Madagascar of trees being unsustainably felled for honey, and poor utilisation of trees for canoes. The Malinke villagers of Bamako, Mali are dependent on forest products, but they view the forest as something alien, to be feared (Sow and Anderson, 1996). Nevertheless, the knowledge and experience of indigenous people should not be dismissed, and may in some cases exceed the extent of Western scientific understanding. Traditional peoples may be particularly valuable for monitoring the effects of climate change (Vlassova, 2006) or alterations to cultural landscapes (Calvo-Iglesias et al., 2006) but pressures from Western society are eroding traditional knowledge sources (Cox, 2000; Jackson, 2004).

7.3. Knowledge transfer

The transfer of traditional knowledge between indigenous groups and into the Western scientific sphere will be especially important in helping communities adapt to climate change, particularly if biomes boundaries move, leaving traditional people in would be effectively a new and alien environment. Indigenous people have often learned from their neighbours, and Turner et al. (2003) describe several such information transfers in Canada. Also in Canada, work has been done to establish a formal ‘adaptive learning’ framework for traditional knowledge transfer (Davidson-Hunt and Berkes, 2003; Davidson-Hunt, 2006). In studying traditional knowledge however, it is important to recognise that traditional methods are neither superior or inferior to Western science, but complementary (Nyong et al., 2007). Attention also needs to be paid to precisely what elements of a society are considered ‘local’ or ‘traditional’ (Davis and Wagner, 2003; Brosius, 2006).

8. INTERRELATIONS BETWEEN FORESTS AND OTHER SYSTEMS/SECTORS

The adaptations of forests to climate change will interact with several other sectors, including agriculture, tourism, legal/regulatory, industry, energy and conservation. This interaction may take three forms; competition for resources, synergies in mitigation/adaptation measures or negative consequences of pro-forest policies.

8.1. Resource competition

The clearest case of resource competition between forestry and other sectors is the simple need for land in developing countries, where forests are in conflict with agriculture (Cullen et al., 2005). This conflict is also becoming apparent in some developed countries. In some places, the governments' policy of supporting plantation development has resulted in much agricultural land being turned over to forests, often against the wishes of many local communities (O'Leary et al., 2000; Woodhead et al., 2004; Seijo, 2005). Mitigation projects involving afforestation may face the same resistance if community support is not gained in advance. Competition for land between forestry and agriculture is becoming heated in Australia, with forestry plantation companies being blamed for pushing land prices up beyond the reach of other producers (NFF, 2006; Apthorp, 2007a). Conversely, in New Zealand a booming dairy industry has resulted in *Pinus radiata* plantations being converted back to agricultural use (Apthorp, 2007b). Land competition is also apparent between forestry and residential use (Radeloff et al., 2005).

Afforestation schemes in some areas have been criticised over the amount of water taken up by the trees, reducing runoff availability for other purposes (Jackson et al., 2005; Klein at al., 2007; Parsons et al., 2007; Brown et al., 2007). In parts of southern Australia, groundwater is a tradable commodity, and timber plantations must compete with agriculture for their water entitlements. This has added $AUD1000 – 1800 to the cost of plantation establishment (Rod Meynink, pers. comm.).

The increasing areas of biofuel plantations can be expected to add to resource-use conflicts (de Fraiture et al., n.d.; Doornbosch and Steenblik, 2007). Sugar cane in Brazil and palm oil in Indonesia (Colchester et al., 2005) are used increasingly for biofuels, and are placing pressure on native forest conservation efforts.

8.2. Synergies

Increasing forest area will most likely often be a part of national mitigation programmes. Depending on management goals, this may potentially also benefit conservation and biodiversity, timber production, recreational opportunities and ecosystem services such as clean water supplies. Tree plantations can lower groundwater table with potential benefits for reducing dryland salinity (Engel et al., 2005; Benyon et al., 2006). Afforestation schemes may be used to clean up contaminated land (Leggo et al., 2006). Soil sequestration of carbon increases fertility, productivity and enhances communities' wealth and adaptive capacity (Lal, 2004).

Recognising the interconnectedness of forests with other sectors can lead to better policy outcomes. Finland's 'forest cluster' concept (Reunala, 2002) serves to bring together the interests of many sectors involved in forestry. This proved to be of great advantage in preparing Finland's National Forest Programme (NFP), as cross-departmental issues such as road infrastructure, research, education, business competitiveness, biodiversity and water protection were all considered to be integral parts of forest policy. There is a risk however, that an increased focus on process can lessen the focus on concrete outcomes for sustainable forest management (Carvalho-Mandes, 2002).

8.3. Policy effects

Polices to increase carbon sequestration in forests may have some negative consequences. Increased water usage can reduce streamflows (Bustier et al., 2007) or, in some environments, bring saline groundwater to the surface (Jobbagy and Jackson, 2004). Increased nutrient usage and soil acidification are also possible (Jackson et al., 2005). Policies that promote new forests for carbon sequestration may have negative consequences for biodiversity (Caparros and Jacquemont, 2003; Holden et al., 2007)

Afforestation may reduce the severity of downstream flooding (Nisbet and Thomas, n.d.) although this effect may sometimes be overstressed (Calder and Aylward, 2006; Calder, 2007), particularly in the case of plantation forests. Afforestation can provide employment benefits in poor areas (Balooni, 2003) but widespread or poorly planned schemes may meet social resistance (Hunter et al., 1998; Kassioumis et al., 2004).

9. INSTITUTIONAL AND POLICY FRAMEWORKS

9.1 Institutional Frameworks

9.1.1 International Policy Agreements

Internationally, policies addressing climate change are broadly organised under the United Nations Framework Convention on Climate Change (UNFCCC). The Conference of the Parties (COP) is the lead body of the UNFCCC, and is an association of all the signatory nations. Two permanent subsidiary bodies were established: the Subsidiary Body for Scientific and Technical Advice (SBSTA) and the Subsidiary Body for Implementation (SBI). These bodies provide technical advice to the COP. One of SBSTA's major concerns is Land-Use, Land-Use Change and Forestry (LULUCF; UNFCCC n.d.a). The first COP in 1995 charged SBSTA with seeking advice from the IPCC, and summarising this and other scientific information for the use of the COP (Pachauri, 2004).

The Kyoto protocol is a free-standing international treaty, linked to the UNFCCC. The protocol commits developed-nation signatories to reducing greenhouse gas emissions, and provides mechanisms for emissions trading, joint implementation and the Clean Development Mechanism (CDM) (UNFCCC n.d.b). A précis of how the UNFCCC and the Kyoto protocol affect national forest policy was given by the Food and Agriculture Organisation (FAO, 2004).

The UNFCCC launched the Nairobi work programme in 2005, to assist with international understanding of the impacts of climate change, mitigation and adaptation. A number of developing nations have developed National Adaptation Programmes of Action (NAPAs) under the umbrella of the UNFCCC.

Other major international agreements that are relevant to forests in the context of climate change include the Convention on Biological Diversity (CBD), the Non-Legally Binding Instrument on Types of Forests agreed by the United Nations Forum on Forests (UNFF), and the Millennium Development Goals (MDG).

9.1.2 Research

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). The IPCC does not conduct research, but is essentially a scientific and political house of review for climate change relevant scientific literature (IPCC, 2003). The IPCC is organised into three working groups and a Task Force on National Greenhouse Gas Inventories. Working Group 1 deals with the scientific basis of climate change, Working Group 2 concentrates on impacts, vulnerability and adaptation and Working Group 3 concentrates on mitigation issues. The Fourth Assessment Report (4AR) of the IPCC comprises several volumes, progressively released through 2007.

The Collaborative Partnership on Forests (CPF) is a partnership between 14 international forestry research organisations (CPF, 2007). The Joint Initiative on Science and Technology was established by the CPF in 2007 to support the UNFF and other forest-related intergovernmental processes and conventions. Part of that support is the Joint Initiative's establishment of an Expert Panel on Adaptation of Forests to Climate Change, which is expected to prepare a report for use by the 8th session of the UNFF in April/May 2009, as well as by the CBD and the UNFCCC.

A wide variety of national and international research bodies and networks are working on projects relevant to the adaptations of forests to climate change. A selection of these are presented in table 2

Location	**Organisation**	**Web address**
Global	IPCC (Intergovernmental Panel on Climate Change)	http://www.ipcc.ch/
Global	ESSP (Earth System Science Partnership)	http://www.essp.org/
Global	CPF (Collaborative Partnership on Forests)	http://www.fao.org/forestry/site/cpf/en/
Global	MRI (Mountain Research Initiative)	http://mri.scnatweb.ch/
Global	IGBP (International Geosphere-Biosphere Programme)	http://www.igbp.net/
Global	GLORIA (Global Observation Research Initiative in Alpine Environments)	http://www.gloria.ac.at/
Europe	EFI (European Forest Institute)	http://www.efi.int/portal/
Americas	IAI (Inter-American Institute for Climate Change Research)	http://www.iai.int/index.php?option=com_frontpage&Itemid=1
Americas	CIRMOUNT (Consortium for Integrated Climate Research in Western Mountains)	http://www.fs.fed.us/psw/cirmount/
USA	USGCRP (US Global Change Research Program)	http://www.usgcrp.gov/usgcrp/nacc/default.htm
USA	USDA (United States Department of Agriculture) Forest Service	http://www.fs.fed.us/research/fsgc/climate-change.shtml
USA	Pew Centre on Global Climate	www.pewclimate.org/
Canada	Canadian Forest Service	http://cfs.nrcan.gc.ca/forestresearch/subjects/climate
Australia	Australian Greenhouse Office	http://www.greenhouse.gov.au/impacts/forests.html
UK	UKCIP (United Kingdom Climate Impacts Programme)	http://www.ukcip.org.uk/about/default.asp
Germany	Potsdam Institute for Climatic Impact Research	http://www.pik-potsdam.de/
Chile	FORECOS	http://www.forecos.net/index.php?len=2

Table 2. Selected research agencies working on issues relevant to the adaptations of forests to climate change.

9.2. Science/Policy Interface and Project Design

Translating science into policy is rarely an easy task, particularly if the science is complicated and uncertain, and policy makers are beset by a range of conflicting interests. Although part of the problem lies in communication, there are a range of issues that need to be addressed in incorporating scientific knowledge in policy decisions. Jones et al. (1999) developed a means of assessing the efficacy of research reports in influencing policy, and found four major conditions that needed to be satisfied:

i) Relevance of research to current decision deliberations,
ii) Compatibility of research results with policy formulation procedures,
iii) Accessibility of research results to policy makers, and
iv) Receptiveness of policy makers to research results.

In their case study involving the effects of climate change on the conflicting needs of the hydro-electricity industry and salmon conservation efforts at Lake Pen d'Oreille in northern Idaho, Jones et al. (1999) found that current research was not well targeted to the decision in hand, climate change research was not in a compatible format with other research data, climate change information was not readily accessible and receptivity was limited due to the high uncertainty of climate scenario parameters.

The British Ecological Society has been actively trying to influence government policy since the late 1960s. Lawton (2007) cites the example of the reductions in sulphur dioxide as an example of the successes ecologists have had in the past (although Jones et al. (1999) cite the same issue as a failure of science to influence policy). Lawton (2007) lists several reasons why translating science into policies is more complex than simply presenting the research results and expecting 'common sense' to prevail, and urges scientists to be aware of the messiness of the policy formulation process. One trap identified by Wilson and Anderson (2006) is a tendency for scientists faced with high levels of uncertainty in their work to offer opinions (sometimes in conflict with other scientist's opinions), which are then presented by vested interests to the public and policy makers as 'the voice of science itself'.

9.3. Policy

9.3.1. Treaty Conflicts

The development of climate change policy is complicated by the sometimes non-complementary or even conflicting nature of the agreements referred to in section 9.1. Pielke (2005) points to differences in definitions of 'climate change' between the UNFCCC and the IPCC, and shows how this could lead to a failure to adequately address adaptation strategies (although FAO (2005a) infers a goal of adaptation in the UNFCCC's mission). The insistence from some bodies that there can be no winners, only losers, from climate change (see Glantz, 2007 and Pielke, 2005) may be understandable from a political perspective in marshalling international support for climate change mitigation measures, but may also lead to a failure to take advantage of possible regional benefits and reduce the impetus of adaptation programmes. Pielke (2005) also points out that the UNFCCC focus is solely on anthropomorphic climate change attributable to greenhouse gas emissions, but neglects important effects such as vegetation changes to albedo (Marland et al., 2003).

Afforestation and reforestation are often presented as mitigation options against climate change, but as Capparos and Jacquemont (2003) discuss, afforestation schemes may in some cases be in conflict with countries' obligations under the CBD, particularly if they involve the use of non-native species or the establishment of plantations on previously unforested land (Hanson et al., 2001).

9.3.2. Policy considerations

Policies for the adaptations of forests to climate change will need to be developed in the traditional framework of 'economic, environmental and social' factors. As discussed throughout this report, each of these factors will come under pressure from climate change, offering both threats and opportunities. Conflict between these three factors is nothing new for forestry, but climate change will open new battlefronts, and complicate existing compromise arrangements. Given the high levels of uncertainty inherent in climate change science, it is likely that much forest management in the future will need to be adaptive management (Maracchi et al., 2005), and managers must be prepared to explore and learn from their actions.

Although the global economic consequences for forests from climate change are broadly optimistic, much of this advantage is predicated on a high level of intervention in natural systems, through salvage harvesting, species replacement and plantation establishment. The positive adaptation of forests to climate change (in an economic sense) will require more intensive management, particularly in regard to the selection of species and provenances best suited to the new climatic conditions (Saxe et al., 2001)

Environmental policies aimed at ensuring maximum biodiversity and the survival of species may also need a high level of management intensity, through changing vegetation structures and communities or altering disturbance regimes. The expansion of reserves to incorporate gradients of different latitudes or elevations would also assist in species migration (WCMC, 1999). Where no other options exist, seed banks, refuge colonies or genetic engineering may be required (Hanson et al., 2001). Recent development in the field of macroecology (Kerr et al., 2007) may provide a new tool for broad-scale forest management.

In developing adaptation projects, several aspects must be considered (FAO, 2005a). These involve institutional, economic, forest management, social and research issues. A project checklist was produced by the Climate, Community and Biodiversity Alliance (CCBA, 2005) that covers general, climate, community and biodiversity issues. The FAO suggests that successful adaptation projects need decentralisation, political willingness, participation of civil society, local-level awareness and transparency in the policy frameworks and policy development processes (FAO, 2005a).

The role of forests in climate change mitigation is recognised by the UNFCCC (UNFCCC, 2002), although by early 2007 only 10 afforestation projects worldwide had been approved (Ruddell et al., 2007). Ruddell et al. (2007) discuss the policy priorities of forestry in future mitigation schemes in the United States, centring on the need to discourage forest conversion to other uses and on sustainable forest management for carbon sequestration. The possible combination of adaptation and mitigation strategies in the forest sector was discussed by Ravindranath (2007).

9.3.3. Anthropomorphic/Management Effects

The importance of the interactions of anthropomorphic effects with climate change cannot be overstressed. This provides opportunities for policymakers, as those anthropomorphic effects (introduction or elimination of species, changing in grazing or fire regimes, chemical depositions etc) are amenable to management (Chapin et al., 2004). Thus, policy decisions over the coming decades will have an immense influence on how forests will adapt to changed climatic conditions.

This may signal a need to move away from the ‘wilderness’ model of reserve management to a more active assessment and interference regime. To quote from Hanson et al. (2001, p. 777),

> “*However, choosing not to control greenhouse gases or not to manage species, communities, and landscapes in the face of climate change is making a decision about the impact of these changes on biodiversity. Rather than letting inaction decide the result of potential changes, active assessment and management will be necessary to bring the landscape to a state of desired future biodiversity conditions in the face of global climate change*.”

9.3.4. Public Attitudes and Support

The inevitability of significant climate change effects is not unanimous (i.e. von Storch and Stehr, 2000), and this may be contributing to a lacking sense of urgency in public opinion about climate change in general, and its effects on forest biomes in particular. In the United Kingdom, many people still recently believed that global warming is not a problem and could possibly be a good thing (Green et al. (eds, 2003)). Holecy and Hanewinkel (2006) point out that insurance against storm damage is still rare in Central Europe, even though storm frequencies and intensities are expected to rise (Hanson et al., 2004), and the effects of the December 1999 European storms (which caused losses of 150-195 million m3 of timber (Bomersheim, 2000)) are still apparent. Nevertheless, an attempt by writers to shift public thinking may lead them to present all ecosystem changes as negative (i.e. Warren et al., 2006; Scholze et al., 2006; Stern, 2007) and thus hinder constructive adaptation measures.

The concept of ‘wilderness’ is difficult to define (see Aplet, 1999), and people’s attitudes towards and images of landscape change with society (Buijs et al., 2006) or with people’s place within society (Andersson, 1993). Floyd et al. (1997) found that people with a high level of environmental concern are less accepting of management impacts on national parks, which could lead to public resistance to assisted species migration schemes and the like. Many authors argue for increasing the resilience of natural ecosystems through reducing the impact of other stressors (WCMC, 1999; Palmesan and Galbraith 2004). It is important that this not be perceived by the public in a simplistic 'human intervention is bad' fashion (see Gillson and Willis, 2004).

Definitions of 'wilderness' generally hinge on the lack of human influence in these areas (see Kalamandeen and Gillson, 2007) although, curiously, biodiversity has been sometimes shown to be positively correlated with human population density in the United States and Australia (Luck et al., 2004). If anthropomorphic climate change has the far-reaching effects described earlier in this report, then these definitions will need to be revisited. At the heart of this debate will be the conflict between the ideals of 'managed' and 'unmanaged' forests. Should forest managers actively intervene in protected areas to assist species migration? Should native species be genetically engineered to better suit anticipated climate regimes? In essence, should forest managers attempt to hold back the tide of biome change in an effort to preserve 20th century ecosystems, let nature and climate change take their course without other interference, or try to decide on an 'ideal' future biome and actively promote its development? This fundamentally philosophical question will underlie much of the forest management debate for the next century, and the success of and support for management programmes will depend on the degree to which management philosophies are in line with public thinking.

10. GLOSSARY

The definitions selected here are primarily taken from the IPCC's Fourth Assessment Report or other IPCC publications. However, where no IPCC definitions exist or where other definitions have been developed that better suit the understanding of this paper, they have been used and references supplied.

ADAPTATION

Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007a).

ADAPTIVE CAPACITY (in relation to climate change impacts)

The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007a).

ADAPTIVE MANAGEMENT

Adaptive management incorporates research into conservation action. Specifically, it is the integration of design, management, and monitoring to systematically test assumptions in order to adapt and learn (Salafsky et al., 2001).

AFFORESTATION

Direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources (IPCC, 2007a).

BIOME

Major and distinct regional element of the biosphere, typically consisting of several ecosystems (e.g., forests, rivers, ponds, swamps) within a region of similar climate. Biomes are characterised by typical communities of plants and animals (IPCC, 2007a).

CLIMATE CHANGE

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer).Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (Pachauri, 2004).

CLIMATE SCENARIOS

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use as input to climate change impact models. A 'climate change scenario' is the difference between a climate scenario and the current climate (IPCC, 2007a).

CLIMATE VARIABILITY

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2007a).

DEFORESTATION

Natural or anthropogenic process that converts forest land to non-forest (IPCC, 2007a).

ENSO

Stands for El Niño–Southern Oscillation. ENSO refers to an irregular cycle of warming and cooling of the sea surface temperatures (see definition) of tropical Pacific Ocean. The cycle has a length of about 4 years, and is a natural part of the Earth's climate system. The oceanic warming and cooling is accompanied by changes in air pressure above the Pacific Ocean (the "Southern Oscillation"). These changes in the Pacific Ocean's temperatures and the atmosphere above it affect the global climate system, and therefore can affect the climate in regions that are far away from the Pacific (like Africa) (IRICS, 2007).

FOREST RESOURCE-DEPENDENT COMMUNITY

"A human society that reside in a comparatively small geographic area in which people rely on the extraction and/or processing of forest-products for their livelihoods" (Definition formulated in this document).

LAND USE AND LAND USE CHANGE

Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction and conservation). Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on the surface albedo, evapo-transpiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus have a radiative forcing and/or other impacts on climate, locally or globally (Baede, 2007).

MITIGATION

An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks (IPCC, 2007a).

NET PRIMARY PRODUCTION

Net primary production is the gross primary production minus autotrophic respiration, i.e., the sum of metabolic processes for plant growth and maintenance, over the same area (IPCC, 2007a).

REFORESTATION

Planting of forests on lands that have previously contained forests but that have been converted to some other use (IPCC, 2007a).

RESILIENCE (community or socioeconomic)

The ability of a community to adapt to change (Daniels, 2004).

SEQUESTRATION (of Carbon)

The process of increasing the carbon content of a reservoir/pool other than the atmosphere (IPCC, 2007a)

UNCERTAINTY

An expression of the degree to which a value (e.g., the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgement of a team of experts) (IPCC, 2007a).

VULNERABILITY (Biophysical)

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

VULNERABILITY (Social)

The ability or inability of individuals and social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being" (Kelly and Adger, 2000).

11. REFERENCES

Adger, WN 1999, Social Vulnerability to Climate Change and Extremes in Coastal Vietnam, *World Development* vol. 27 (2), pp. 249-269

Adger, WN, Brooks, N, Bentham, G, Agnew, M and Eriksen, S 2004, *New indicators of vulnerability and adaptive capacity*, Technical Report 7, Tyndall Centre for Climate Research, Norwich

Adger, WN, Huq, S, Brown, K, Conway, D and Hulme, M 2003, Adaptation to climate change in the developing world, *Progress in Development Studies* vol. 3, pp. 179-195

Ahas, R, Aasa, A, Menzel, A, Fedotova, G and Scheifinger, H 2002, Changes in European Spring phenology, *International Journal of Climatology* vol. 22, pp. 1727-1738

Ainsworth, EA and Long, SP 2005, What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2, *New Phytologist* vol. 165, pp. 351-371

Andersson, T 1993, *Views on Nature in Metaphorical Discourse*, online at http://www.lucs.lu.se/ftp/pub/LUCS_Studies/LUCS%206.pdf accessed 07 December 2007

Aplet, GH 1999, On the Nature of Wilderness: Exploring What Wilderness Really Protects, *Denver University Law Review* vol. 76 (2), pp. 347-368

Apthorp, B 2007a, $10,000 a hectare being paid for prime forestry land, *Friday Offcuts* 9 November 2007

Apthorp, B 2007b, *Friday Offcuts* 9 November 2007

Arsenault, D andf Payette, S 1997, Reconstructions of millennial forest dynamics from tree remains in a subarctic tree line peatland, *Ecology* vol. 78 (6), pp. 1873-1883

Assoff, R, Zotz, G and Körner, C 2006, Growth and phenology of mature forest trees in elevated CO2, *Global Change Biology*, vol. 12, pp, 848-861

Ayers, MP and Lombardero, MJ 2000, Assessing the consequences of global change for forest disturbance from herbivores and pathogens, *The Science of the Total Environment* vol. 262, pp. 263-286

Bachelet, D, Lenihan, J, Neilson, R, Drapek, R and Kittle, T 2005, Simulating the response of natural ecosystems and their fire regimes to climatic variability in Alaska, *Canadian Journal of Forest Research* vol. 35, pp. 2244-2257

Bachelet, D and Neilson, R 2001, Biome redistribution under climate change, in *The Impact of Climate Change on America's Forests*, LA Joyce and R Birdsey (eds), Technical Report RMRS-GTR-59, USDA Forest Service, Fort Collins

Bachelet, D, Neilson, RP, Lenihan, JM and Drapek, RJ 2001, Climate Change Effects on Vegetation Distribution and Carbon Budget in the United States, *Ecosystems* vol. 4, pp. 164-185

Bachelet, D, Neilson, RP, Lenihan, JM and Drapek, RJ 2004, Regional Differences in the Carbon Source-Sink Potential of Natural Vegetation in the U.S.A., *Environmental Management* vol. 33 (S1), pp. S23-S43

Badeck, FW, Bondeau, A, Böttcher, K, Doktor, D, Lucht, W, Schaber, J and Sitch, S 2004, Responses of spring phenology to climate change, *New Phytologist* vol. 162, pp. 295-309

Baede, APM 2007, Annex 1: Glossary. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bael, D and Sedjo, RA 2006, *Toward Globalization of the Forest Products Industry Some Trends*, RFF DP 06-35, Resources For the Future, Washington, online at http://www.rff.org/documents/RFF-DP-06-35.pdf accessed 12 December 2007

Baker, RHA, Sansford, CE, Jarvis, CH, Cannon, RJC, MacLeod, A and Walters, KFA 2000, The role of climatic mapping in predicting the potential geographical distribution of non-indigenous pests under current and future climates, *Agriculture, Ecosystems and Environment* vol. 82, pp. 57-71

Balooni, K 2003, Economics of wastelands afforestation in India, a review, *New Forests* vol. 26, pp. 101-136

Barber, VA, Juday, GP and Finney, BF 2000, Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress, *Nature* vol. 405 (6787), pp. 668-673

Bartolome, E, Belward, AS, Achard, F, Bartalev, S, Carmona-Moreno, C, Eva, H, Fritz, S, Gregoire, JM, Mayaux, P and Stibig, HJ 2002, *GLC2000: Global Land Cover mapping for the year 2000, Project status November 2002*, European Commission Joint Research Centre Institute for Environment and Sustainability, Ispra, online at http://www-gvm.jrc.it/glc2000/Publications/GLC2000%20EUR20524_report_v2.pdf accessed 23 November 2007

Becker, CD and Ghimire, K 2003, Synergy Between Traditional Ecological Knowledge and Conservation Science Supports Forest Preservation in Ecuador, *Conservation Ecology* vol. 8 (1)

Beckley, TM 1998, The nestedness of forest-dependence: A conceptual framework and empirical exploration, *Society and Natural Resources* vol. 11 (2), pp. 101-120

Beckley, TM 2000, *Sustainability for Whom? Social Indicators for Forest-dependant Communities in Canada*, Sustainable Forest Management Network, University of Alberta, Edmonton

Beckley, TM, Stedman, RC, Wallace, S and Ambard, M 2004, *A new tool for understanding sense of place*, Project Reports 2003/2004, Sustainable Forest Management Network, online at http://www.sfmnetwork.ca/docs/e/PR_200304beckleytunde6.pdf accessed 02 November 2007

Bell, JL, Sloan, LC and Snyder, MA 2004, Regional Changes in Extreme Climatic Events: A Future Climate Scenario, *Journal of Climate* vol. 17, pp. 81-87

Benyon, RG, Theiveyanathan, S and Doody, TM 2006, Impacts of tree plantations on groundwater in south-eastern Australia, *Australian Journal of Botany* vol. 54, pp. 181-192

Berch, P, Costello, C, Fortmann, L and Hoffmann, S 2003, Poverty and Employment in Forest-Dependent Counties, *Forest Science* vol. 49 (5), pp. 763-777

Berglund, BE, Barnekow, L, Hammarlund, D, Sandgren, P and Snowball, IF 1996, Holocene forest dynamics and climate changes in the Abisko area, northern Sweden: The Sonesson model of vegetation history reconsidered and confirmed, *Ecol. Bull.* Vol 45, pp. 15-30

Berry, SL and Roderick, ML 2006, Changing Australian vegetation from 1788 to 1988: effects of CO2 and land use change, *Australian Journal of Botany* vol. 54, pp. 325-338

Bhatt, PSCP 2003, In forestry lies the prospect of economic progress, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

Boedhihartono, AK, Gunarso, P, Levang, P and Sayer, J 2007, The Principles of Conservation and Development: Do they apply in Malinau?, *Ecology and Society* vol. 12 (2)

Boisvenue, C and Running, SW 2006, Impacts of climate change on natural forest productivity – evidence since the middle of the 20th century

Bomersheim, WP 2000, *After the Storms: Impact of the December 1999 Storms which Hit Europe*, online at http://www.fas.usda.gov/ffpd/wood-circulars/jun00/europe.pdf accessed 06 December 2007

Bond, W 2003, Tree/grass dynamics in a changing world, in *Global Climate Change and Biodiversity*, RE Green, M Hartley, L Miles, J Scharlemann, A Watson and O Watts (eds), Tyndall Center for Climate Change Research, Norwich

Bond, WJ, Woodward, FI and Midgley, GF 2005, The global distribution of ecosystems in a world without fire, *New Phytologist* vol. 165, pp. 525-538

Booth, TH, Nghia, NH, Kirschbaum, MUF, Hackett, C and Jovanovic, T 1999, Assessing possible impacts of climate change on species important for forestry in VietNam, *Climatic Change* vol. 41, pp. 109-126

Boucher, TV and Mead, BR 2006, Vegetation change and forest regeneration on the Kenai Peninsular, Alaska following a spruce beetle outbreak, 1987-2000, *Forest Ecology and Management* vol. 227, pp. 233-246

Bouchon, E and Arseneault, D 2004, Fire disturbance during climate change: failure of postfire forest recovery on a boreal floodplain, *Canadian Journal of Forest Research* vol. 34, pp. 2294-2305

Bowman, D 2005, Understanding a flammable planet – climate, fire and global vegetation patterns, *New Phytologist* vol. 165, pp. 341-345

Bradley, NL, Leopold, AC, Ross, J and Huffaker, H 1999, Phenologícal changes reflect climate change in Wisconsin, *Proceedures of the National Academiy of Sciences of the United States* vol. 96, pp. 9701-9704

Bradshaw, RHW, Holmqvist, BH, Cowling, SA and Sxkes, MT 2000, The effects of climate change on the distribution and management of Picea abies in southern Scandinavia, *Canadian Journal of Forest Research* vol. 20 (12)

Briles, CE, Whitlock, C and Bartlein, PJ 2005, Postglacial vegetation, fire, and climate history of the Siskixou Mountains, Oregon, USA, *Quaternary Research* vol. 64, pp. 44-56

Brockington, D 2007, Forests, Community Conservation, and Local Government Performance: The Village Forest Reserves of Tanzania, *Society and Natural Resources* vol. 20 (9), pp. 835-848

Brosius, JP 2006, What counts as Local Knowledge in Global Environmental Assessments and Conventions?, in Reid, WV, Berkes, F, Wilbanks, T and Capistrano, D (eds), *Bridging Scales and Knowledge Systems*, Island Press, Washington DC

Brovkin, V, Claussen, M, Driesschaert, E, Fichefet, T, Kicklighter, D, Loutre, MF, Mathews, HD, Ramankutty, N, Schaeffer, M and Sokolov, A 2006, Biogeophysical effects of historical land cover changes simulated by six Earth system models of intermediate complexity, *Climate Dynamics* vol. 26, pp. 587-600

Brown, AE, Podger, GM, Davidson, AJ, Dowling, TI and Zhang, L 2007, Predicting the impact of forestry on water users at local and regional scales An example for the Murrumbidgee River Basin, Australia, *Forest Ecology and Management* vol. 251, pp. 82-93

Brown, PM 2006, Climate effects on fire regimes and tree recruitment in Black Hills Ponderosa pine forests, *Ecology* vol. 87 (10), pp. 2500-2510

BRS 2003, *Australia's State of the Forests Report 2003*, Bureau of Rural Sciences, Canberra

Buijs, AE, Pedroli, B and Luginbühl, Y 2006, From hiking through farmland to farming in a leisure landscape: changing social perceptions of the European landscape, *Landscape Ecology* vol. 21, pp. 375-389

Burton, DM, McCarl, BA, de Sousa, CNM, Afams, DM, Alig, R and Winnett SM 1997, *Economic Impacts of Climate Change on Southern Forests*, Faculty Paper FP 97-18, Department of Agricultural Economics, Texas A&M University, College Station, online at http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid=425&ftype=.pdf accessed 24 Oct 2007

Buytaert, W, Iniguez, V and de Bievre, B 2007, The effects of afforestation and cultivation on water yield in the Andean paramo, *Forest Ecology and Management* vol. 251, pp. 22-30

Byron, RN and Arnold, JEM 1999, What futures for the people of the tropical forests? *World Development* vol. 27 (5), pp. 789-805

Caccianiga, M and Payette, S 2006, Recent advance of white spruce (*Picea glauca*) in the coastal tundra of the eastern shore of Hudson Bay (Quebec, Canada), *Journal of Biogeography* vol. 33, pp. 2120-2135

Calder, IR 2007, Forests and water – Ensuring forest benefits outweigh water costs, *Forest Ecology and Management* vol. 251, pp. 110-120

Calder, IR and Aylward, B 2006, Forests and Floods: Moving to an Evidence-based Approach to Watershed and Integrated Flood Management, *Water International* vol. 31 (1), pp. 1-13

Callaghan, TV, Werkman, BR and Crawford, RMM 2002, The tundra-taiga interface and its dynamics: concepts and applications, *Ambio Special Report 12*, pp. 6-14

Calvo-Iglesias, MS, Crecente-Maseda, R and Fra-Paleo, U 2006, Exploring farmer's knowledge as a source of information on past and present cultural landscapes A case study from NW Spain, *Landscape and Urban Planning* vol. 78, pp. 334-343
Sow, M and Anderson, J 1996, Perceptions and of woodland by Malinke villagers near Bamako, Mali, *Unasylva* vol. 47 (186)

Camerero, JJ and Gutierrez, E 2004, Pace and pattern of recent treeline dynamics: response of ecotones to climate variability in the Spanish Pyrenees, *Climatic Change* vol. 63, pp. 181-200

Cane, MA 2005, The evolution of El Niño, past and future, *Earth and Planetary Science Letters* vol. 230 (3–4), pp. 227–240

Capparos, A and Jacquemont, F 2003, Conflicts between biodiversity and carbon sequestration programs: economic and legal implications, *Ecological Economics* vol. 46, pp. 143-157

Cardellichio, P, Youn, Y, Adams, D, Joo, D and Chmelik, J 1989, *A Preliminary Analysis of Timber and Timber Products Production, Consumption, Trade and Prices in the Pacific Rim until 2000*, CINTRAFOR Working Paper 22, College of Forest Resources, University of Washington, Seattle

Carroll, AL, Taylor, SW, Regniere, J and Safranyik, L 2004, *Effects of Climate Change on Range Expansion by the Mountain Pine Beetle in British Columbia*, Mountain Pine Beetle Symposium: Challenges and Solutions, October 30-31, 2003, Kelowna, British Columbia, TL Shore, JE

Brooks and JE Stone (eds), Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Information Report BC-X-399, Victoria

Carroll, MS 1995, *Community and the Northwestern logger: Continuities and changes in the era of the spotted owl*, Rural Studies Series, Westview Press, Boulder

Carvalho-Mendez, AMS 2002, Evaluation of Supporting and Impeding Factors of National Forest Programmes, in *Cross-Sectoral Policy Impacts on Forests*, EFI Proceedings 46, I Tikkanen, P Glück and H Pajuoja (eds), European Forest Institute, Joensuu

Castellanos, JG 2006, *Tropical forest response to climate change*, online at http://www.dumac.org/dumac/habitat/esp/notas/notas_julio/Cambio_Climatico_ingles.pdf accessed 09 November 2007

CCBA 2005, *Climate, Community and Biodiversity Project Design Standards*, Climate, Community and Biodiversity Alliance, Washington, online at http://www.climate-standards.org/images/pdf/CCBStandards.pdf accessed 06 December 2007

Chapin, FS III, Callaghan, TV, Bergeron, Y, Fukoda, M, Johnstone, JF, Juday, G and Zimov, SA 2004, Global Change and the Boreal Forest: Thresholds, Shifting States or Gradual Change?, *Ambio* vol. 33(6), pp. 361-365

Chen, X and Pan, W 2002, Relationships among phonological growing season, time-integrated normalized difference vegetation index and climate forcing in the temperate region of eastern China, *International Journal of Climatology* vol. 22, pp. 1781-1792

Christensen, JH., Hewitson, B, Busuioc, A. Chen, A, Gao, X, Held, I, Jones, R, Kolli, K, Kwon, WT, Laprise, R, Magaña Rueda, V, Mearns, L, Menéndez, CG, Räisänen, J, Rinke, A, Sarr, A and Whetton, P 2007, Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Chung, CH, Lim, HS and Yoon, HI 2006, Vegetation and climate changes during the Late Pleistocene to Holocene inferred from pollen record in Jinju area, South Korea, *Geosciences Journal* vol. 10 (4), pp. 423-431

Ciais, P (and 32 others) 2005, Europe-wide reduction in primary productivity caused by the heat and drought in 2003, *Nature* vol. 437, pp. 529-533

CIRMOUNT Committee 2006, *Mapping New Terrain: Climate Change and America's West*, Report of the Consortium for Integrated Climate Research in Western Mountains (CIRMOUNT), Misc. Pub., PSW-MISC-77, Albany, CA, Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture

Clark, DA 2007, Detecting Tropical Forests' Responses to Global Climatic and Atmospheric Change: Current Challenges and a Way Forward, *Biotropica* vol. 39(1), pp. 4-19

Clark, JS, Fastie, C, Hurtt, G, Jackson, ST, Johnson, C, King, GA, Lewis, M, Lynch, J, Pacala, S, Prentice, C, Schupp, EW, Webb, T and Wyckoff, P 1998, Reid's paradox of rapid plant migration – Dispersal theory and interpretation of palaeocological records, *Bioscience* vol. 48 (1), pp. 13-25

Claussen, M 1996, Variability of Global Biome Patterns as a Function of Initial and Boundary Conditions in a Climate Model, *Climate Dynamics* vol. 12, pp. 371-379

Cleland, EE, Chuine, I, Menzel, A, Mooney, HA and Schwartz, MD 2006, Shifting plant phenology in response to global change, *Trends in Ecology and Evolution* vol. 22 (7), pp. 357-365

Climate Leadership Initiative Institute for a Sustainable Environments 2007, *Economic impacts of climate change on forest resources in Oregon, a preliminary analysis*, Bauman, Y and Wolf, E (eds), University of Oregon, online at http://climlead.uoregon.edu/publicationspress/OR%20Forest%20Resources%20FINAL%205.11.07.pdf accessed 24 October 2007

Colchester, M 1996, Beyond "participation": indigenous peoples, biological diversity conservation and protected area management, *Unasylva* vol. 47 (187)

Colchester, M, Jiwan, N, Andiko, Sirait, M, Firdaus, AY, Surambo, A and Pane, H 2005, *Promised Land: Palm Oil and Land Acquisition in Indonesia: Implications for Local Communities and Indigenous Peoples*, Forest Peoples Programme, Moreton-on-Marsh and Perkumpulan Sawit Watch, Bogor

Collingham, YC and Huntley, B 2000, Impacts of Habitat Fragmentation and Patch Size upon Migration Rates, *Ecological Applications* vol. 10 (1), pp. 131-144

Cordell, HK, Bergstrom, JC, Hartmann, LA and English, DBK *An analysis of the outdoor recreation and wilderness situation in the United States: 1989-2040,* General Technical Report RM-189, USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado,1990

Cosgrove, R, Field, J and Ferrier, A 2007, The archaeology of Australia's tropical rainforests, *Palaeogeography, Palaeoclimatology, Palaeoecology* vol. 251, pp. 150-173

Cowling, SA, Sykes, MT and Bradshaw, RHW 2001, Paleovegetation-model comparisons, climate change and tree succession in Scandinavia over the past 1500 years, *Journal of Ecology* vol. 89, pp. 227-236

Cox, PA 2000, Will Tribal Knowledge Survive the Millennium?, *Science* vol. 287 (5450), pp. 44-45

CPF 2007, *Collaborative Partnership on Forests,* Collaborative Partnership on Forests, online at http://www.fao.org/forestry/site/cpf/en/ accessed 05 December 2007

ESSP 2005, *Planning Workshop Report on African Network for Global Environmental Change Research*, 22-24 September 2005, Earth Systems Science Partnership, online at http://www.gwsp.uni-bonn.de/downloads/GCR_Report.pdf accessed 03 December 2007

Cullen, L Jr, Alger, K and Rambaldi, DM 2005, Land Reform and Biodiversity Conservation in Brazil in the 1990s: Conflict and the Articulation of Mutual Interests, *Conservation Biology* vol. 19 (1), pp. 747-755

Currie, DJ 2001, Projected effects of climate change on patterns of vertebrate and tree species richness in the coterminous United States, *Ecosystems* vol. 4, pp. 216-225

Curtis, PS and Wang, X 1998, A meta analysis of elevated CO_2 effects on woody plant mass, form, and physiology, *Oecologia* vol. 113, pp. 299-313

Daily GC, Alexander S, Ehrlich PR, Goulder L, Lubchenco J, Matson PA, Mooney HA, Postel S, Schneider SH, Tilman D, Woodwell GM 1997, Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology* vol. 2

Dale, VH (and 13 others) 2001, Climate Change and Forest Disturbances, *BioScience* vol. 51 (9), pp. 723-734

Dang, H, Gillett, NP, Weaver, AJ and Zwiers, FW 2007, Cliimate change detection over different land surface vegetation classes, *International Journal of Climatology* vol. 27, pp. 211-220

Daniels, JM 2004, *Assessing socio-economic resiliency in Washington Counties*, General Technical Report PNW-GTR-607, USDA Forest Service, Portland

Davidson, DJ, Williamson, T, Parkins, JR 2003, Understanding climate change risk and vulnerability in northern forest-based communities, *Canadian Journal of Forest Research* vol. 33, pp. 2252-2261

Davidson-Hunt, IJ 2006, Adaptive Learning Networks: Developing Resource Management Knowledge through Social Learning Forums, *Human Ecology* vol. 34 (4), pp. 593-614

Davidson-Hunt, I and Berkes, F 2003, Learning as You Journey: Anishinaabe Perception of Social-ecological Environments and Adaptive Learning, *Conservation Ecology* vol. 8 (1)

Davis, A and Wagner, JR 2003, *Who* Knows? On the Importance of Identifying “Experts” When Researching Local Ecological Knowledge, *Human Ecology* vol. 31 (3), pp. 463-489

Davis, MB and Zabinski, C 1992, Changes in geographical range resulting from greenhouse warming: Effects on biodiversity in forests, in RL Peters and TE Lovejoy (eds), *Global Warming and Biological Diversity*, Yale University Press, New Haven

de Dios, VR, Fischer, C and Colinas, C 2007, Climate change effects on Mediterranean forests and preventative measures, *New Forests* vol. 33, pp. 29-40 de Fraiture, C, Giordano, M and Yongsong, L n.d., Biofuels and implications for agricultural water use: blue impacts of green energy, online at http://www.iwmi.cgiar.org/EWMA/files/papers/Biofuels%20-%20Charlotte.pdf accessed 28 November 2007

de Jong, TJ and Klinkhamer, PGL 2005, *Evolutionary Ecology of Plant Reproductive Strategies*, Cambridge University Press, Cambridge

Denman, KL, Brasseur, G, Chidthaisong, A, Ciais, P, Cox, PM, Dickinson, RE, Hauglustaine, D, Heinze, C, Holland, E, Jacob, D, Lohmann, U, Ramachandran, S, da Silva Dias, PL, Wofsy, SC and Zhang, X 2007, Couplings Between Changes in the Climate System and Biogeochemistry. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

de Steiguer, JE and McNulty, SG 1988, An Integrated Assessment of Climate Change on Timber Markets of the Southern United States, in *The Productivity and Sustainability of Southern Forest Ecosystems in a Changing Environment*, Mickler and Fox (eds), Springer-Verlag, New York

Dewulf, A, François, G, Pahl-Wohl, C and Tailliew, T 2007, A Framing Approach to Cross-Disciplinary Research Collaboration: Experiences from a Large-scale Research Project on Adaptive Water Management, *Ecology and Society* vol. 12 (2)

Doornbosch, R and Steenblik, R 2007, *Biofuels: Is the cure worse than the disease?*, SG/SD/RT(2007)3, Organisation for Economic Co-operation and Development Round Table on Sustainable Development, online at http://media.ft.com/cms/fb8b5078-5fdb-11dc-b0fe-0000779fd2ac.pdf accessed 28 November 2007

Dorland, C, Tol, RSJ and Palutikof 1999, Vulnerability of the Netherlands and Northwest Europe to storm damage under climate change, *Climatic Change* vol. 43, pp. 513-535

Dukes, J 2003, Hotter and weedier? Effects of climate change on the success of invasive species, in *Global Climate Change and Biodiversity*, RE Green, M Hartley, L Miles, J Scharlemann, A Watson and O Watts (eds), Tyndall Center for Climate Change Research, Norwich

Eakin, H and Luers, AL 2006, Assessing the Vulnerability of Social-Environmental Systems, *Annual Review of Environment and Resources*, vol. 31, pp. 365-394

Easterling, W and Apps, M 2005, Assessing the consequences of climate change for food and forest resources: a view from the IPCC, *Climatic Change* vol. 70, pp. 165-189

Easterling, WE, Aggarwal, PK, Batima, P, Brander, KM, Erda, L, Howden, SM, Kirilenko, A, Morton, J, Soussana, J, Schmidhuber, FJ and Tubiello, FN 2007, Food, fibre and forest products. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge

EEA 2004, *Impacts of Europe's changing climate an indicator based assessment,* European Environment Agency, Luxemburg

EFI 2000 *EFI Proceedings No 34, Expert Assessment of the Likely Impacts of Climate Change on Forests and Forestry in Europe*, Kellomäki, S, Karjalainen, T, Mohren, F and Lapveteläinen, T, Eds, European Forest Institute

Ellison, AM and Farnsworth, EJ 1996, Anthropogenic disturbance of Caribbean mangrove ecosystems: past impacts, present trends and future predictions, *Biotropica* vol. 28, pp. 549-565

Ellison, J 2003, Climate change and sea level rise impacts on mangrove ecosystems, in *Global Climate Change and Biodiversity*, RE Green, M Hartley, L Miles, J Scharlemann, A Watson and O Watts (eds), Tyndall Center for Climate Change Research, Norwich

Engel, V, Jobbagy, EG, Steiglitz, M, Williams, M and Jackson, RB 2005, Hydrological consequences of eucalyptus afforestation in the argentine pampas, *Water Resources Research* vol. 41 (10)

Fagan, B 2000, *Floods, Famines and Emperors; El Niño and the Fate of Civilizations,* Pimlico, London

FAO 2004, *Climate change and the forest sector, possible national and subnational legislation*, Food and Agriculture Organisation of the United Nations, Rome

FAO 2005a, *Adaptation of forest ecosystems and the forest sector to climate change*, Food and Agriculture Organisation of the United Nations, Rome

FAO 2005b, Enhancing the role of forests in achieving the Millennium Development Goals, *Unasylva* vol. 56 (220)

Fearnside, PM 1995, Potential impacts of climatic-change on natural forests and forestry in Brazilian Amazonia, *Forest Ecology and Management* vol. 78 (1-3), pp.

Fearnside, PM 1999, Plantation forestry in Brazil: the potential impacts of climate change, *Biomass and Bioenergy* vol. 16, pp. 91-102

Fearnside, PM 2001, Saving tropical forests as a global warming countermeasure: an issue that divides the environmental movement, *Ecological Economics* vol. 39 (2), pp. 167-184

Fearnside, PM 2004, Are climate change impacts already affecting tropical forest biomass?, *Global Environmental Change* vol. 14 (4), pp.

Feddema, JJ, Oleson, KW, Bonan, GB, Mearns, LO, Buja, LA, Meehl, GA and Washington, WM 2005, The Importance of Land-Cover Change in Simulating Future Climates, *Science* vol. 310, pp. 1674-1678

Feeley, KJ, Wright, SJ, Supardi, MNN, Kassim, AR and Davies, SJ 2007, Decelerating growth in tropical forest trees, *Ecology Letters* vol. 10, pp. 461-469

Fensham, RJ and Fairfax, RJ 1996, The Disappearing Grassy Balds of the Bunya Mountains, South-eastern Queensland, *Aust. J. Bot.* vol. 44, pp. 543-558

Fensham, RJ, Fairfax, RJ and Archer SR 2005, Rainfall, land use and woody vegetation cover changes in semi-arid Australian savanna. *Journal of Ecology*, vol. 93, pp. 596-606

Fernandes, PM and Rigolot, E 2007, The fire ecology and management of maritime pine (*Pinus pinaster* Ait.), *Forest Ecology and Management* vol. 241, pp. 1-13

Feurdean, A 2005, Holocene forest dynamics in northwestern Romania, *The Holocene* vol. 15 (3), pp. 435-446

Few, R 2003, Flooding, vulnerability and coping strategies: local responses to a global threat, *Progress in Development Studies* vol. 3 (1), pp. 43-58

Few, R 2007, Health and climatic hazards: Framing social research on vulnerability, response and adaptation, *Global Environmental Change* vol. 17, pp. 281-295

Fisher, M 2004, Household welfare and forest dependence in Southern Malawi, *Environment and Development Economics* vol. 9, pp. 135-154
Food and Agriculture Organisation of the United Nations 1995, *Forest Products*, FAO, Rome

Flannigan, MD, Amiro, BD, Logan, KA, Stocks, BJ and Wotton, BM 2005, Forest fires and climate change in the 21st century, *Mitigation and Adaptation Strategies for Global Change* vol. 11, pp. 847-859

Flannigan, MD, Stocks, BJ and Wotten, BM 2000, Climate change and forest fires, *The Science of the Total Environment* vol. 262, pp. 221-229

Flenley, JR 1998, Tropical forests under the climates of the last 30,000 years, *Climatic Change* vol. 39, pp. 177-197

Flint, CG 2006, Community perspectives on spruce beetle impacts on the Kenai Peninsular, Alaska, *Forest Ecology and Management* vol. 227, pp. 207-218

Floyd, MF, Jang, H and Noe, FP 1997, The Relationship Between Environmental Concern and Acceptability of Environmental Impacts among Visitors to Two U.S. National Park Settings, *Journal of Environmental Management* vol. 51, pp. 391-412

Forests Monitor 2007, *The Timber Trade and Poverty Alleviation. Upper Great Lakes Region*, online at http://www.forestsmonitor.org/uploads/2e90368e95c9fb4f82d3d562fea6ed8d/Timber_Trade_and_Poverty_Alleviation_in_the_Upper_Great_Lakes.pdf accessed 29 October 2007 accessed 29 October 2007

Forest Peoples Project 2007, *Annual Report 2006*, Forest Peoples Project, online at http://www.forestpeoples.org/documents/ann_rep/fpproj_ar_06.pdf accessed 03 November 2007

Forner, C nd, *Will forests survive in the adaptation debate? Linking ecosystem services to development and adaptation policies*, online at http://www.c3d-unitar.org/UserFiles/File/AIDCO/Presentations%20in%20PDF%20format/Forner%20backgrounder%20on%20forest%20ecosystems%20and%20adaptation.pdf accessed 29 October 2007

Fotelli, MN, Rudolph, P, Rennenberg, H and Geßler, A 2005, Irradiance and temperature affect the competetive interference of blackberry on the physiology of European beech seedlings, *New Phytlogist* vol. 165, pp. 453-462

Fraser Institute 2007, *Independent Summary for Policymakers IPCC Fourth Assessment Report*, The Fraser Institute, Vancouver

Garcia-Barrios, L and Gonzalez-Espinosa, M 2004, Change in oak to pine dominance in secondary forests may reduce shifting agriculture yields: experimental evidence from Chiapas, Mexico, *Agriculture, Ecosystems and Environment* vol. 102, pp. 389-401

Gillson, L and Willis, KJ 2004, 'As Earth's testimonies tell': wilderness conservation in a changing world, *Ecology Letters* vol. 7, pp. 990-998

Gilmour, D, Malla, Y and Nurse, M 2004, *Linkages between community forestry and poverty*, Regional Community Forestry Training Center for Asia and the Pacific, Bangkok

Glantz, MH 2007, Oh! What a Lovely Climate Change: Global Warming's Winners and Losers, *Fragilecologies*, online at http://www.fragilecologies.com/aug21_07.html accessed 04 December 2007

Gleik, PH 2000, *Climate Variability and Change for the Water Resources of the United States*, Pacific Institute for Studies in Development, Environment, and Security, Oakland, online at http://www.gcrio.org/NationalAssessment/water/water.pdf accessed 31 October 2007

Goosse, H, Arzel, O, Luterbacher, J, Mann, ME, Renssen, H, Riedwyl, N, Timmermann, A, Xoplaki, E and Wanner, H 2006, The origin of the European "Medieval Warm Period", *Climate of the Past* vol. 2, pp. 99-113

Govender, N, Trollope, WSW and Van Wilgen, BW 2006, The effect of fire season, fire frequency, rainfall and management on fire intensity in savanna vegetation in south Africa, *Journal of Applied Ecology* vol. 43, pp. 748-758

Grace, J, Berninger, F and Nagy, L 2002, Impacts of Climate Change on the Tree Line, *Annals of Botany* vol. 90, pp. 537-544

Green, RE, Hartley, M, Miles, L, Scharlemann, J, Watson, A and Watts, O (eds) 2003, *Global Climate Change and Biodiversity*, Tyndall Center for Climate Change Research, Norwich

Griffiths, T 2001, *Forests of Ash: An Environmental History*, Cambridge University Press, Melbourne

Griffiths, T 2007, *Seeing 'RED'? 'Avoided deforestation' and the rights of Indigenous Peoples and local communities*, Forest Peoples Program, online at http://www.forestpeoples.org/documents/ifi_igo/avoided_deforestation_red_jun07_eng.pdf accessed 29 October 2007

Groisman, PY (and 12 others) 2007, Potential forest fire danger over Northern Eurasia: Changes during the 20th century, *Global and Planetary Change* vol. 56, pp. 371-386

Groisman, PY, Knight, RW, Easterling, DR, Karl, TR, Hegerl, GC and Razuvaev, VN 2005, Trends in intense precipitation in the climate record, *Journal of Climate* vol. 18, pp. 1343-1367

Grosnow, J 2003, Review of poverty alleviation through forestry activity, in *Proceedings*, *FAO Advisory Committee on Paper and Wood Products, forty-fourth session*, Oaxaca, Mexico, 8–9 May 2003, FAO, Rome

Gunwan, B, Takeuchi, K, Tsunekawa, A and Abdoellah, OS 2004, Community Dependency on Forest Resources in West Java, Indonesia: The Need to Re-Involve Local People in Forest Management, *Journal of Sustainable Forestry* vol. 18 (4), pp. 29-46

Halsnaes, K and Verhagen, J 2007, Development based climate change adaptation and mitigation – conceptual issues and lessons learned in studies in developing countries, *Mitigation and Adaptation Strategies for Global Change* vol. 12, pp. 665-684

Hansen, AJ, Neilson, RP, Dale, VH, Flather, CH, Iverson, LR, Currie, DJ, Shafer, S, Cook, R and Bartlein, PJ 2001, Global Change in Forests: Responses of Species, Communities, and Biomes, *BioScience* vol. 51 (9), pp. 765-779

Hanson, CE, Holt, T and Palutikof, JP 2004, *An Integrated Assessment of the Potential for Change in Storm Activity over Europe: Implications for Insurance and Forestry in the UK*, Tyndall Centre for Climate Change Research, online at http://www.tyndall.ac.uk/research/theme3/final_reports/it1_4.pdf accessed 06 December 2007

Hantemirov, RM and Shiyatov, SG 2001, A continuous multimillennial ring-width chronology in Yamal, northwestern Siberia, *The Holocene* vol. 12 (6), pp. 717-726

Hauer, G, Weber, M and Price, D 2004, *Climate Change Impacts on agriculture/forestry land use patterns: Developing and applying an integrated economy-ecosystem response and adaptation impacts assessment model.* Online at http://adaptation.nrcan.gc.ca/projdb/pdf/77_e.pdf accessed 11 December 2007

Hauer, G, Williamson, T and Renner, M 2001, *Socioeconomic impacts and adaptive responses to climate change: a Canadian forest sector perspective*, Information Report NOR-X-373, Natural Resources Canada, Canadian Forest Service; Northern Forestry Centre, Edmonton

Haxeltine, A and Prentice, IC 1996, BIOME3: An Equilibrium Terrestrial Biosphere Model Based on Ecophysiological Constraints, Resource Availability, and Competition Among Plant Functional Types, *Global Biogeochemical Cycles* vol. 10 (4), pp. 693-709

Haynes, RW 2003, *Assessing the viability and adaptability of forest-dependent communities in the United States*, General Technical Report PNW-GTR-567, USDA Forest Service Pacific Northwest Research Station, Portland

Helama, S, Lindholm, M, Timomen, M and Eronen, M 2005, Mid- and late Holocene tree population dnsity changes in northern Fennoscandia derived by a new method using megafossil pines and their tree-ring series, *Journal of Quaternary Science* vol. 20 (6), pp. 567-575

Hemp, A 2005, Climate change-driven forest fires marginalize the impact of ice cap wasting on Kilimanjaro, *Global Change Biology* vol. 11, pp. 1013-1023

Hessl, AE and Baker, WL 1997, Spruce and Fir Regeneration and Climate in the Forest-Tundra Ecotone of Rocky Mountain National Park, Colorado, U.S.A., *Arctic and Alpine Research* vol. 29, pp. 173-183

Hicke, J.A, Asner, GP, Randerson, JT, Tucker, C, Los, S, Birdsey, R, Jenkins, JC and Field, C 2002, Trends in North American net primary productivity derived from satellite observations, 1982–1998, *Global Biogeochemical Cycles* vol. 16 (2)

Hicke, JA, Logan, JA, Powell, J and Ojima, DS 2006. Changing temperatures influence suitability for modeled mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in the western United States, *Journal of Geophysical Research* vol. 111 (G2)

Higgins, SI, Lavorel, S and Revilla, E n.d., Estimating plant migration rates under habitat loss and fragmentation, GCTE (Global Change Terrestrial Ecosystems), online at http://www.gcte.org/HigginsLavorelRevilla.pdf accessed 14 November 2007

Hoek, WZ 2001, Vegetation response to the ~14.7 and ~11.5 ka cal. BP climate transitions: is vegetation lagging climate?, *Global and Planetary Change* vol. 30 (1-2), pp. 103-115

Holden, J and 15 others 2007, Environmental change in moorland landscapes, *Earth-Science Reviews* vol. 82, pp. 75-100

Holecy, J and Hanewinkel, M 2006, A forest management risk insurance model and its application to coniferous stands in southwest Germany, *Forest Policy and Economics* vol. 8, pp. 161-174

Hughes, L 2003, Climate Change and Australia: Trends, Projections and Impacts. *Austral Ecology* vol. 28, pp. 423-443

Hughes, L, Cawsey, EM and Westoby, M 1996, Climatic Range Sizes of Eucalyptus Species in Relation to Climate Change, *Global Ecology and Biogeography Letters* vol. 5 (1), pp. 23-29

Hunt, S, Newman, J and Otis, G 2006, *Threats and impacts of exotic pests under climate change: implications for Canada's forest ecosystems and carbon stocks*, Biocap Canada, online at http://www.biocap.ca/rif/report/Hunt_S.pdf accessed 14 November 2007

Hunter, IR, Hobley, M and Smale, P 1998, Afforestation of degraded land – Pyrrhic victory over economic, social and ecological reality?, *Ecological Engineering* vol. 10 (1), pp. 97-106

Huntley, B 2003, Effects of climate change on Arctic vegetation, in *Global Climate Change and Biodiversity*, RE Green, M Hartley, L Miles, J Scharlemann, A Watson and O Watts (eds), Tyndall Center for Climate Change Research, Norwich

Hyvönen, R, Ägren, GI, Linder, S, Persson, T, Cotrufo, MF, Ekblad, A, Freeman, M, Grelle, A, Janssens, IA, Jarvis, PG, Kellomäki, S, Lindroth, A, Loustau, D, Lundmark, T, Norby, RJ, Oren, R, Pilegaard, K, Ryan, MG, Sigurdsson, BD, Strömgren, M, van Oijen, M and Wallin, G 2007, The likely impact of elevated [CO_2], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: a literature review. *New Phytologist* vol. 173, pp. 463-480

Ibanez, I, Clark, JS, LaDeau, S and Lambers, JHR 2007, Exploiting temporal variability to understand tree recruitment response to climate change, *Ecological Monographs* vol. 77 (2), pp. 163-177

Innes, JL and Hickey, GM 2006, The importance of climate change in considering the role of forests in the alleviation of poverty, *International Forestry Review* vol. 8 (4), pp. 406-416

IPCC (Intergovernmental Panel Climate Change) 2001, *Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Intergovernmental Panel on Climate Change Third Assessment Report*, eds. JJ McCarthy, OF Canziani, NA Leary, DJ Dokken and KS White, Cambridge University Press, Cambridge

IPCC 2003, Procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of IPCC Reports Appendix A, online at http://www.ipcc.ch/pdf/ipcc-principales/ipcc-principales-appendix-a.pdf Accessed 13 January 2008

IPCC, 2007a: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds, Cambridge University Press, Cambridge, UK, 976pp.

IPCC 2007b, Summary for Policymakers, In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IRICS (International Research Institute for Climate and Society) 2007, *Glossary of Terms Related to Climate and Climate Forecasts*, online at http://iri.columbia.edu/outreach/meeting/MediaWS2001/Glossary.html accessed 14 January 2008

Irland, LC 2000, Ice storms and forest impacts, *The Science of the Total Environment* vol. 262, pp. 231-242

Irland, LC, Adams, D, Alig, R, Betz, CJ, Chen, C, Hutchins, M, McCarl, BA, Skog, K and Sohngen, BL 2001, Assessing Socioeconomic Impacts of Climate Change on US Forests, Wood-Product Markets, and Forest Recreation, *Bioscience* vol. 51 (9), pp. 753-764

Iverson, LR and Prasad, AM 1998, Predicting abundance for 80 tree species following climate change in the eastern United States, *Ecological Monographs* vol. 68 (4), pp. 465-485

Iverson, LR and Prasad, AM 2001, Potential Changes in Tree Species Richness and Forest Community Types following Climate Change, *Ecosystems* vol. 4, pp. 186-199

Iverson, LR, Schwartz, MW and Prasad, AM 2004, Potential colonization of newly available tree-species habitat under climate change: an analysis for five eastern US species, *Landscape Ecology* vol. 19, pp. 787-799

Jackson, D 2004, *Implementation of international commitments on traditional forest-related knowledge: Indigenous peoples' experiences in Central Africa*, Forest Peoples Programme, online at http://www.forestpeoples.org/documents/africa/tfrk_expert_mtg_oct04_eng.pdf accessed 30 November 2007

Jackson, RB, Jobbagy, EG, Avissar, R, Roy, SB, Barrett, DJ, Cook, CW, Farley, KA, le Maitre, DC, McCarl, BA and Murray, BC 2005, Trading Water for Carbon with Biological Carbon Sequestration, *Science* vol. 310, pp. 1944-1947

Jahren, AH 2007, The Arctic Forest of the Middle Eocene, *Annual Reviews of Earth and Planetary Sciences* vol. 35, pp. 509-540

Jansen, E, Overpeck, J, Briffa, KR, Duplessy, J-C, Joos, F, Masson-Delmotte, V, Olago, D, Otto-Bliesner, B, Peltier, WR, Rahmstorf, S, Ramesh, R, Raynaud, D. Rind, D, Solomina, O, Villalba, R and Zhang, D 2007, Palaeoclimate. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jobbagy, EG and Jackson, RB 2004, Groundwater use and salinization with grassland afforestation, *Global Change Biology* vol. 10, pp. 1299-1312

Johnstone, JF and Chapin, FS III 2003, Non-equilibrium succession dynamics indicate continued northern migration of lodgepole pine, *Glob. Change. Biol.* Vol. 9, pp. 1401-1409

Jolly, WM, Nemani, R and Running, SW 2005, A generalized, bioclimatic index to predict foliar phenology in response to climate, *Global Change Biology* vol. 11, pp. 619-632

Jones, SA, Fischhoff, B and Lach, D 1999, Evaluating the science-poilicy interface for climate research, *Climatic Change* vol. 43, pp. 581-599

Joyce, LA and Birdsey, R 2000, (eds), *The Impact of Climate Change on America's Forests*, Technical Report RMRS-GTR-59, USDA Forest Service, Fort Collins

Joyce, LA, Mills, JR, Heath, LS, McGuire, AD, Haynes, RD and Birdsey, RA 1995, Forest sector impacts from changes in forest productivity under climate change, *Journal of Biogeography* vol. 22, pp. 703-713

Joyce, LA and Nungesser, M 2000, Ecosystem Productivity and the Impact of Climate Change, in *The Impact of Climate Change on America's Forests*, LA Joyce and R Birdsey (eds), Technical Report RMRS-GTR-59, USDA Forest Service, Fort Collins

Kalamandeen, M and Gillson, L 2007, Demything "wilderness": implications for protected area designation and management, *Biodiversity Conservation* vol. 16, pp. 165-182

Kaplan, JO and 17 others 2003, Climate change and Arctic ecosystems: 2. Modeling, paleodata-model comparisons, and future projections, *Journal of Geophysical Research* vol. 108 (D19)

Kapralov, D, Shiyatov, S, Moiseev, P and Fomin, V 2006, Changes in the composition, structure, and altitudinal distribution of low forests at the upper limit of their growth in the Northern Ural Mountains, *Russian Journal of Ecology*, vol 37 (6), pp. 367-372

Karnosky, DF 2003, Impacts of elevated atmospheric CO2 on forest trees and forest ecosxstems: knowledge gaps, *Environment International* vol. 29, pp. 161-169

Kassioumis, K, Papageorgiou, K, Christodoulou, A, Blioumis, V, Stamou, N and Karameris, A 2004, Rural development by afforestation in predominantly agricultural areas: issues and challenges from two areas in Greece, *forest Policy and Economics* vol. 6, pp. 483-496

Keatley, MR, Fletcher, TD, Hudson, IL and Ades, PK 2002, Phenological studies in Australia: potential application in historical and future climate analysis, *International Journal of Climatology*, vol. 22, pp. 1769-1780

Kelly, PM and Adger, WN 2000, Theory and practice in assessing vulnerability to climate change and facilitating adaptation, *Climatic Change* vol. 47, pp. 325-352

Kelly, EN, Schindler, DW, St.Louis, VL, Donald, DB and Vladicka, KE 2006, Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs, *Proceedings of the National Academy of Sciences of the United States of America* vol. 103 (51), pp. 19380-19385

Kempter, H, Görres, M and Frenzel, B 1997, Ti and Pb concentrations in rainwater-fed bogs in Europe as indicators of past anthropogenic activities, *Water, Air and Soil Pollution* vol 100, pp. 367-377

Kennealy, P, Hartarska, V, Bailey, C and Dubois, M 2006, Timberland Ownership and Social Well-Being in the South, Paper presented at the 2006 meetings if the Rural Sociological Society, Louisville, Kentucky, 10-13 August 2006, online at http://www.ruralsociology.org/annual-meeting/2006/proceedings/Keenealy,etal.pdf accessed 01 November 2007

Kerr, JT, Kharouba, HM and Currie, DJ 2007, The Macroecdological Contribution to Global Change Solutions, *Science* vol. 316 (5831), pp. 1581-1584

Kirschbaum, MUF 2004, *Assessing Climate-Change Impacts of Forest Productivity*, Powerpoint presentation for CSIRO Forestry and Forest Products & CRC for Greenhouse Accounting, Canberra, online at http://www.dar.csiro.au/csiroclimate/Docs/Kirschbaum.ppt#1 accessed 25 October 2007

Klein, RJT, Huq, S, Denton, F, Downing, TE, Richels, RG, Robinson, JB and Toth, FL 2007, Inter-relationships between adaptation and mitigation, in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (Eds)., Cambridge University Press, Cambridge, UK, 745-777.

Kleine, M and Roberts, G 2007, *Adaptations of Forests and the Forest Sector to Climate Change Preparatory Study* , Joint Initiative on Science and Technology, Vienna, online via http://www.iufro.org/science/science-initiative/resources/ Accessed 13 January 2008

Kohut, R 2003, The long-term effects of carbon dioxide on natural systems: issues and research needs, *Environment International*, vol. 29, pp. 171-180

Kräuchi, N 1993, Potential impacts of a climate change on forest ecosystems, *European Journal of Forest Pathology* vol. 23, pp. 28-50

Kullman, L 2002, Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes, Journal of Ecology vol. 90, pp. 68–77

Lal, R 2004, Soil carbon sequestration impacts on global climate change and food security, *Science* vol. 304, pp. 1623-1627

Lamb, HH 1995, *Climate, History and the Modern World*, Routledge, London

Lawton, JH 2007, Ecology, politics and policy, *Journal of Applied Ecology* vol. 44, pp. 465-474

Lee, DM and Lyon, KS 2004, A Dynamic Analysis of the Global Timber Market under Global Warming: An Integrated Modeling Approach, *Southern Economic Journal* vol. 70 (3), pp. 467-489

Leggo, PJ, LeDesert, B and Christie, G 2006, The role of clinoptilolite in organo-zeolitic-soil systems used for phytoremediation, *Science of the Total Environment* vol. 363, pp. 1-10

Lemmen, DS and Warren, FJ (eds) 2004, *Climate Change Impacts and Adaptation: A Canadian Perspective*, Natural Resources Canada, Ottawa

Le Treut, H, Somerville, R, Cubasch, U, Ding, Y, Mauritzen, C, Mokssit, A, Peterson, T and Prather, M 2007, Historical Overview of Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the*

Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lewis, SL, Malhi, Y and Phillips, OL 2004, Fingerprinting the impacts of global change on tropical forests, *Philosophical Transactions of the Royal Society of London* vol. 359, pp. 437-462

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

Linderholm, HW 2006, Growing season changes in the last century, *Agricultural and Forest Meteorology* vol. 137, pp. 1-14

Logan, JA, Regniere, J and Powell, JA 2003, Assessing the impacts of global warming on forest pest dynamics, *Frontiers in Ecology and the Environment* vol. 1, pp. 130-137

Loomis, J and Crespi, J 1999, Estimated effects of climate change on selected outdoor recreation activities in the United States, in Mendelsohn and Neuman (eds), *The Impact of Climate Change on the United States Economy*, Cambridge University Press, Cambridge

Loope, LL and Giambelluca 1998, Vulnerability of island tropical montane cloud forests to climate change, with special reference to East Maui, Hawai'i, *Climatic Change* vol. 39, pp. 503-517

Luck, GW, Ricketts, TH, Daily, GC and Imhoff, M 2004, Alleviating spatial conflict between people and biodiversity, *Procedures of the National Academy of Sciences* vol. 101 (1), pp. 182-186

Luckman, BH 1994, Evidence for climatic conditions between c.900-1300 AD in the southern Canadian Rockies, *Climatic Change* vol. 26 (2-3), pp. 171-182

Lunt, ID 2002, Grazed, burnt and cleared: how ecologists have studied century-scale vegetation changes in Australia, *Aust. J. Bot.*, vol. 50, pp. 391-407

Lynam, T, Cunliffe, R and Mapaure, I 2004, Assessing the Importance of Woodland Landscape Locations for Both Local Communities and Conservation in Gorongosa and Muanza Districts, Sofala Province, Mozambique, *Ecology and Society* vol. 9 (4), art. 1

Lynch, AH, Beringer, J, Kershaw, P, Marshall, A, Mooney, S, Tapper, N, Turney, C and Van Der Kaars, S 2007, Using the Paleorecord to Evaluate Climate and Fire Interactions in Australia, *Annual Reviews of Earth and Planetary Sciences* vol. 35, pp. 215-239

MacDonald, GM (and 13 others) 2000, Holocene Treeline History and Climate Chamge Across Nothern Eurasia, *Quaternary Research* vol. 53, pp. 302-311

Malcolm, JR 2003, Models of the global impact of climate change on biodiversity and adaptive responses, in *Global Climate Change and Biodiversity*, RE Green, M Hartley, L Miles, J Scharlemann, A Watson and O Watts (eds), Tyndall Center for Climate Change Research, Norwich

Malcolm, J and Pitelka, L 2000, *Ecosystems and Global Climate Change: A Review of Potential Impacts on U.S. Terrestrial Ecosystems and Biodiversity*, Pew Center on Global Climate Change, Arlington

Mamo, G, Sjaastad, E and Vedeld, P 2007, Economic dependence on forest resources: A case from Dendi District, Ethiopia, *Forest Policy and Economics* vol. 9 (8), pp. 916-927

Mann, ME 2007, Climate Over the Past Two Millennia, *Annual Reviews of Earth and Planetary Science* vol. 35, pp. 111-136

Manter, DK, Reeser, PW and Stone, JK 2005, A Climate-Based Model for Predicting Geographic Variation in Swiss Needle Cast Severity in the Oregon Coast Range, *Phytopathology* vol. 95, pp. 1256-1265

Maracchi, G, Sirotenko, O and Bindi, M 2005, Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe, *Climatic Change* vol. 70, pp. 117-135

Marland, G and 18 others 2003, The climatic impacts of land surface change and carbon management and the implications for climate-change mitigation policy, *Climate Policy* vol. 3 (2), pp. 149-157

Matsumoto, K, Ohta, T, Irasawa, M and Nakamura, T 2003, Climate change and extension of the *Ginkgo biliba* L. growing season in Japan, *Global Change Biology* vol. 9, pp. 1634-1642

Mayle, FE, Lanfstroth, RP, Fisher, RA and Meir, P 2007, Long-term forest-savannah dynamics in the Bolivian Amazon: implications for conservation, *Philosophical Transactions of the Royal Society of London B-Biological Sciences* vol. 362 (1478) pp. 291-307

Mazepa, VS 2005, Stand density in the last millennium at the upper tree-line ecotone in the Polar Ural Mountains, *Canadian Journal of Forest Research* vol. 35 (9), pp. 2082-2091

McCarl, BA, Adams, DM, Alig, RJ, Burton, D and Chen, C 2000, Effects of global climate change on the US forest sector: response functions Derived from a dynamic resource and market simulator, *Climate Research* vol. 15, pp. 195-205

McDonough, MH and Parker, JD 1995, *Natural Resources and Communities*, Special Report 82, Ag Experimantal Station Special Reports, Michigan State University Extension, online at http://web1.msue.msu.edu/imp/modsr/03279582.html accessed 01 November 2007

MEA (Millennium Ecosystem Assessment) 2005, *Ecosystems and Human Well-being: Biodiversity Synthesis*, World Resources Institute, Washington

Meehl, GA, Stocker, TF, Collins, WD, Friedlingstein, P, Gaye, AT, Gregory, JM, Kitoh, A, Knutti, R, Murphy, JM, Noda, A, Raper, SCB, Watterson, IG, Weaver, AJ and Zhao, Z-C 2007, Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Menzel, A 2000, Trends in phonological phases in Europe between 1951 and 1996, *Int. J. Biometeorol.*, vol. 44, pp. 76-81

Menzel, A and 30 others 2006, European phonological response to climate change matches the warming pattern, *Global Change Biology* vol. 12, pp. 1969-1976

Meshinev, T, Apostolova, I. and Koleva, E 2000, Influence of warming on timberline rising: a case study on *Pinus peuce* Griseb. in Bulgaria, *Phytocoenologia* vol. 30, pp. 431-438

Metzo, KR 2001, Adapting capitalism: Household plots, forest resources, and moonlighting in post-Soviet Siberia, *GeoJournal* vol. 54, pp. 549-556

Meyer, GA and Pierce, JL 2003, Climatic controls on fire-induced sediment pulses in Yellowstone National Park and central Idaho: a long-term perspective, *Forest Ecology and Management* vol. 178, pp. 89-104

Miller, P, Mitchell, M and Lopez, J 2005, Climate Change: Length of Growing-Season in the U.S. Corn Belt, 1911-2000, *Physical Geography* vol. 26 (2), pp. 85-98

Molyneux, DH 2003, Climate change and tropical disease: Common themes in changing vector-borne disease scenarios, *Transactions of the Royal Society of Tropical Medicine and Hygiene* vol. 97, pp. 129-132

Mooney, SD and Maltby, EL 2006, Two proxy records revealing the late Holocene fire history at a site on the central coast of New South Wales, Australia, *Austral Ecology* vol. 31 (6), pp. 682-695

Moran, D 2001, Exile and exclusion: The legacy of soviet forestry for villages in the north of Perm oblast, *GeoJournal* vol. 54, pp. 541-547

Mott, JA, Mannino, DM, Alverson, CJ, Kiyu, A, Hashim, J, Lee, T, Falter, K and Redd, SC 2005, Cardiorespiratory hospitalizations associated with smoke exposure during the 1997 Southeast Asian forest fires, *International Journal of Hygiene and Environmental Health* vol. 208 (1-2), pp. 75-85

Mueller-Dombois, D and Ellenberg, H 1974, *Vegetation types: A consideration of available methods and their suitability for various purposes,* Technical Report 49, Island Ecosystems IRP. U.S. International Biological Program, online at http://www.botany.hawaii.edu/faculty/duffy/ibp/49.pdf accessed 22 November 2007

Naurzbaev, MM, Vaganov, EA, Sidorova, OV and Schweingruber, FH 2002, Summer temperatures in eastern Taimyr inferred from a 2427-year late-Holocene tree-ring chronology and earlier floating series, *The Holocene* vol. 12 (6), pp. 727-735

Neilson, RP 1995, A model for predicting continental-scale vegetation distribution and water balance, *Ecological Applications* vol. 5 (2), pp. 362-385

Nemani, R, Keeling, CD, Hashimoto, H, Jolly,WM and Piper, SC 2003, Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999, *Science* vol. 300 (5625), pp. 1560-1563

Nemani, R and Running, S 1996, Implementation of a hierarchical global vegetation classification in ecosystem function models, *Journal of Vegetation Science* vol. 7 (3)

Neuvonen, S, Niernela, P and Virtanen, T 1999, Climatic change and insect outbreaks in boreal forests the role of winter temperatures, *Ecological Bulletins* vol. 47, pp. 63-67

NFF 2006, *Consultation on Proposed Taxation Arrangements for Plantation Forestry*, National Farmers Federation, online at
http://www.treasury.gov.au/documents/1122/PDF/058_National_Farmers_Federation.PDF
accessed 28 November 2007

Nisbet, TR and Thomas, H n.d., *The role of woodland in flood control: a landscape perspective*, online at http://www.uf.a.u-tokyo.ac.jp/~kuraji/BR/iufro/IUFRO-5.pdf accessed 29 November 2007

Norby, RJ, Wullschleger, SD, Gunderson, CA, Johnson, DW and Ceulemans, R 1999, Tree responses to rising CO2 in field experiments: implications for the future forest, *Plant, Cell and Environment* vol. 22, pp. 683-714

Nunn, PD, Hunter-Anderson, RH, Carson, MT, Thomas, F, Ulm, S and Rowland, MJ 2007, Times of Plenty, Times of Less: Last-Millennium Societal Disruption in the Pacific Basin, *Human Ecology* vol. 35, pp. 385-401

Nyong, A, Adesina, F and Osman-Elasha, B 2007, The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel, *Mitigation and Adaptation Strategies for Global Change* vol. 12, pp. 787-797

Ogden, NH, Maarouf, A, Barker, IK, Bigras-Poulin, M, Lindsay, LR, Morshed, MG, O'Callaghan, CJ, Ramay, F, Waltner-Toews, D and Charron, DF 2006, Climate change and the potential for range expansion of the Lyme disease vector *Ixodes scapularis* in Canada, *International Journal for Parasitology* vol. 36, pp. 63-70

Oksanen, T, Pajari, B and Tuomasjukka, T (eds) 2003, *Forests in Poverty Reduction Strategies: Capturing the Potential*, EFI Proceedings No. 47, European Forest Institute

O'Leary, TN, McCormack, AG and Clinch, JP 2000, Afforestation in Ireland – regional differences in attitude, *Land Use Policy* vol. 17 (1), pp. 39-48

Olson, JS, Watts, JA and Alison, LJ 1983, Carbon in Live Vegetation of Major World Ecosystems, Rep No. ORNL-5862, Oak Ridge National Laboratory, Oak Ridge TN

Overpeck, JT, Rind, D and Goldberg, R 1990, Climate-induced changes in forest disturbance and vegetation, *Nature* vol. 343, pp. 51-53

Pachauri, RK 2004, *16 Years of Scientific Assessment in Support of the Climate Convention*, Intergovernmental Panel on Climate Change, Geneva

Pan, Y, McGuire, AD, Melillo, JM, Kicklighter, DW, Sitch, S and Prentice, IC 2002, A biogeochemistry-based dynamic vegetation model and its application along a moisture gradient in the continental United States, *Journal of Vegetation Science* vol. 13, pp. 369-382

Parkins, JR and MacKendrick, NA 2007, Assessing community vulnerability: A study of the mountain pine beetle outbreak in British Columbia, Canada, *Global Environmental Change* vol. 17, pp. 460-471

Parkins, JR and White, B 2007, *Assessment of Forest Dependant Communities: A Scoping Report*, Social Science Research Group, Canadian Forest Service, Edmonton, online at http://www.ccmf.org/archives/CCFMFDCscopingreport.pdf accessed 29 October 2007

Parmesan, C 2006, Ecological and Evolutionary Responses to Recent Climate Change, *Annu. Rev. Ecol. Evol. Syst.* Vol 37, pp. 637-669

Parmesan, C and Galbraith, H 2004, *Observed Impacts of Global Climate Change in the US*, Pew Center on Global Climate Change,

Parmesan, C and Yohe, G 2003, A globally coherent fingerprint of climate change impacts across natural systems, *Nature*, vol. 421, pp. 37-42

Parsons, M, Frakes, I and Gerrand, A 2007, *Plantations and Water Use*, Bureau of Rural Sciences, Canberra

Pederson, DC, Peteet, DM, Kurdyla, D and Guilderson, T 2005, Medieval Warming, Little Ice Age and European Impact on the environment during the last millennium in the lower Hudson Valley, New York, USA, *Quaternary Research* vol. 63, pp. 238-249

Peng, C 2000, From static biogeographical model to dynamic global vegetation model: a global perspective on modelling vegetation dynamics, *Ecological Modelling* vol. 135 (1), pp. 33-54

Perez-Garcia, J, Joyce, L, Binkley, CS and McGuire, AD 1997, Economic Impacts of Climate Change on the Global Forest Sector, *Critical Rev. Environ. Technol.* vol. 27, pp. S123-S138

Perez-Garcia, J, Joyce, L, McGuire, AD and Xiao, X 2002. Impacts of climate change on the global forest sector. *Climatic Change* vol. 54, pp. 439–461

Pfister, C, Bradzil, R and Barriendos, M 2002, *PAGES News* vol. 10 (3), pp. 6-8

Phillips, OL, Malhi, Y, Higuchi, N, Laurance, WF, Nunez, PV, Vasquez, RM, Laurance, SG, Ferreira, LV, Stern, M, Brown, S and Grace, J 1998, Changes in the carbon balance of tropical forests: evidence from long-term plots, *Science* vol. 282 (5388), pp. 439-442

Piao, SL, Fang, JY, Zhou, LM, Zhu, B, Tan, K and Tao, S 2005, Changes in vegetation net primary productivity from 1982 to 1999 in China, *Global Biogeochemical Cycles* vol. 19 (2), pp.

Pielke, RA Jr 2005, Misdefining "climate change": consequences for science and action, *Environmental Science and Policy* vol. 8, pp. 548-561

Poschen, P and Lövgren, M 2001, *Globalization and Social Sustainability – The Forestry and Wood Industry on the Move*, International Labour Office, online at http://www.unece.org/trade/timber/docs/tc-59/presentations/1-poschen.pdf accessed 12 December 2007

Prinn, RG (and 13 others) 1999, Integrated Global System Model for Climate Policy Assessment: Feedbacks and Sensitivity Analysis, *Climate Change* vol. 41, pp. 469-546

Pyke, CR and Andelman, SJ 2007, Land use and land cover tools for climate adaptation, *Climate Change*, vol. 80, pp. 239-251

Radeloff, VC, Hammer, RB and Stewart, SI 2005, Rural and Suburban Sprawl in the U.S. Midwest from 1940 to 2000 and Its Relation to Forest Fragmentation, *Conservation Biology* vol. 19 (3), pp. 793-805

Raison, J, Eamus, D, Gifford, R and McGrath, J 2007, *The feasibility of forest free air CO2 enrichment (FACE) Experimentation in Australia*, Report prepared by Ensis for the Australian Greenhouse Office, Canberra

Randall, DA, Wood, RA, Bony, S, Colman, R, Fichefet, T, Fyfe, J, Kattsov, V, Pitman, A, Shukla, J, Srinivasan, JR, Stouffer, RJ, Sumi A and Taylor, KE 2007, Climate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ratsifandrihamanana, AN, Montanye, D and Christiansen, S 2006, Socioeconomic Root Causes of Biodiversity Loss in Madagascar, in *Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere*, C Aguirre-Bravo, PJ Pellicane, DP Burns and S Draggan (eds), 2004 September 20-24 Proceedings RMRS-P-42CD, U.S. Department of Agriculture, Fort Collins

Ravindranath, NH 2007, *Mitigation and Adaptation Strategies for Global Change* vol. 12, pp. 843-853

Ravindranath, NH, Joshi, NV, Sukumar, R and Saxena, A 2006, Impact of climate change on forests in India, *Current Science* vol. 90 (3), pp.354-361

Rawat, RBS and Uniyal RC 2003, Non-wood forest produce (NWFP) for poverty reduction, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

RealClimate 2007, *Regional Climate Projections*, RealClimate, online at http://www.realclimate.org/index.php/archives/2007/08/regional-climate-projections/ accessed 11 December 2007

Reunala, A 2002, Finland's National Forest Programme 2010 – a Policy Framework to Balance the Demands for Socio-Economic and Ecological Sustainability, in *Cross-Sectoral Policy Impacts on Forests*, EFI Proceedings 46, I Tikkanen, P Glück and H Pajuoja (eds), European Forest Institute, Joensuu

Richardson, AD, Bailey, AS, Denny, EG, Martin, CW and O'Keefe, J 2006, Phenology of a northern hardwood forest canopy, *Global Change Biology* vol. 12, pp. 1174-1188

Richardson, RB and Loomis, JB n.d. The effects of climate change on mountain tourism: a contingent behaviour methodology, online at http://www.world-tourism.org/sustainable/climate/pres/robert-richardson.pdf accessed 31 October 2007

Ritchie, JC 1995, Current trends in studies of long-term plant community dynamics, *New Phytologist* vol. 130, pp. 469-494

Rolim, SG, Jesus, RM, Nascimento, HEM, do Couto, HTZ and Chambers, JQ 2005, Biomass change in an Atlantic tropical moist forest: the ENSO effect in permanent sample plots over a 22-year period, *Oecologia* vol. 142 (2), pp238-246

Rose A, Cao, Y and Oladosu, G 2000, Simulating the regional economic impacts of climate change in the mid-Atlantic region, *Climate Research* vol. 14 (3), pp 175–183

Ruddell, S and 12 others 2007, The Role for Sustainably Managed Forests in Climate Change Mitigation, *Journal of Forestry* September 2007, pp. 314-319

Running, SW, Loveland, TR, Pierce, LL, Nemani, RR and Hunt, ER Jnr 1995, A Remote Sensing Based Classification Logic for Global Land Cover Analysis, *Remote Sens. Environ.*, vol. 51, pp 39-48

Russell, WMS 1988, Population, swidden farming and the tropical environment, *Population and Environment* vol. 10 (2), pp. 77-94

Sakulich, J and Taylor, AH 2007, Fire regimes and forest structure in a sky island mixed conifer forest, Guadalupe Mountains National Park, Texas, USA, *Forest Ecology and Management* vol. 241, pp. 62-73

Salafsky, N 1994, Drought in the rain-forest – Effects of the 1991 El-Nino-Southern Oscillation event on a rural economy in West-Kalimantan, Indonesia, *Climatic Change* vol. 27 (4), pp. 373-396

Salafsky, N, Margoluis, R and Redford, K 2001 *Adaptive Management: A Tool for Conservation Practitioners.* Washington, D.C.: Biodiversity Support Program online at http://fosonline.org/resources/Publications/AdapManHTML/Adman_1.html accessed 14 January 2008

Salinger, MJ 2005, Climate variability and change: past present and future – an overview, *Climatic Change* vol. 90, pp. 9-29

Sarewitz, D, Pielke, R Jnr and Keykhah, M 2003, Vulnerability and Risk: Some Thoughts from a Political and Policy Perspective, *Risk Analysis* vol. 24 (4), pp. 805-810

Savarino, J and Legrand, M 1998, High northern latitude forest fries and vegetation emissions over the last millennium inferred from the chemistry of a central Greenland ice core, *Journal of Geophysical Research – Atmospheres* vol. 103 (D7), pp. 8267-8279

Saxe, H, Cannell, MGR, Johnsen, O, Ryan, MG and Vourlitis, G 2001, Tree and forest functioning in response to global warming, *New Phytologist* vol. 149, pp. 369-400

Scheller, RM and Mladenoff, DJ 2007, An ecological classification of forest landscape simulation models: tools and strategies for understanding broad-scale forested ecosystems, *Landscape Ecology* vol. 22, pp. 491-505

Schimel, DS, Vemap Paticipants and Braswell, BH 1997, Continental Scale Variability in Ecosystem Processes: Models, Data and the Role of Disturbance, *Ecological Monographs* vol. 67 (2), pp. 251-271

Schimel, DS (and 29 others) 2001, Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems, *Nature* vol. 414, pp. 169-172

Schlesinger, ME and Zhou, ZC 1989, Seasonal Climate Changes Induced by Doubles CO_2 as Simulated by the OSU Atmospheric GCM-Mixed Layer Ocean Model, *Journal of Climate* vol. 2 (2), pp. 459-521

Schneider, SH, Semenov, S, Patwardhan, A, Burton, I, Magadza, CHD, Oppenheimer, M, Pittock, AB, Rahman, A, Smith, JB, Suarez, A and Yamin, F 2007, Assessing key vulnerabilities and the risk from climate change. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK

Scholze, M, Knorr, W, Arnell, NW and Prentice, IC 2006, A climate change risk analysis for world ecosystems, *Proceedings of the National Academy of Sciences* vol. 103 (35), pp. 13116-13120

Schulze, ED and 19 others 1999, Productivity of forests in the Eurosiberian boreal region and their potential to act as a carbon sink – a synthesis, *Global Change Biology* vol. 5, pp. 703-722

Schvidenko, A and Goldammer, JG 2001, Fire situation in Russia, *International Forest Fire News* vol. 24, pp. 41-59

Schwartz, M 1991, Potential effects of global climate change on the biodiversity of plants, *Forestry Chronicle* vol. 68, pp. 462-471

Schwartz, MD 1998, Green-wave phenology, *Nature* vol. 394, pp. 839–840

Schwartzman, S and Zimmerman, B 2005, Conservation Alliances with Indigenous Peoples of the Amazon, *Conservation Biology* vol. 19 (3), pp. 721-727

Schwierz, C, Appenzeller, C, Davies, HC, Liniger, MA, Müller, W, Stocker, TF and Yoshimori, M 2006, Challenges posed by and approaches to the study of seasonal-to-decadal climate variability, *Climatic Change* vol. 79, pp. 31-63

Sedjo, RA and Lyon, KS 1990, *The long term adequacy of world timber supply*. Resource for the Future, John Hopkins University Press, Baltimore

Seijo, F 2005, The Politics of Fire: Spanish Forest Policy and Ritual Resistance in Galicia, Spain, *Environmental Politics* vol. 14 (3), pp. 380-402

Shafer, SL, Bartlein, PJ and Thompson, RS 2001, Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios, *Ecosystems* vol. 4, pp. 200-215

Sharma, RC 2003, Forest for poverty alleviation: Chhattisgarh experience, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

Shougong, Z, Weichang, L, Wenming, L and Huafeng, d 2003, Community forestry in mountain development: a case study in Guizhou Province, China, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

SilviStrat 2005, *Research Notes 163, Management of European Forests under Changing Climatic Conditions*, Kellomäki, S and Leinonen, S, Eds, University of Joensuu Faculty of Forestry, Joensuu.

Singh, KD 2003, Forest and poverty: a survey study, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

Singh, R 2003 Forests for poverty alleviation, the Orissa experience, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

Sisak, L and Pulkrab, K 2002, Estimate of economic impacts of climate change upon Czech forestry, *Journal of Forest Science* vol. 48 (11), pp. 499-507

Smit, B and Pilifosova, O, 2001, Adaptation to climate change in the context of sustainable development and equity, in *Climate Change 2001: Impacts, Adaptation and Vulnerability: Working Group II*, Third Assessment Report, IPCC, Cambridge, UK, Cambridge University Press

Snyder, PK, Delire, C and Foley, JA 2004, Evaluating the influence of different vegetation biomes on the global climate, *Climate Dynamics* vol. 23, pp. 279-302

Sohngen, B, Alig, R and Solberg, B 2007, *The forest sector, climate change, and the global carbon cycle – Environmental and economic implications*, online at http://aede.osu.edu/people/sohngen.1/forests/Forestry_Climate_Survey_2007_v4.pdf accessed 27 October 2007

Sohngen, B and Mendelsohn, R 1999, Valuing the Impact of Large-Scale Ecological Change in a Market: The Effect of Climate Change on U.S. Timber, *The American Economic Review* vol. 88 (4), pp. 686-710

Sohngen, B, Mendelsohn, R and Sedjo, R 2001, A Global Model of Climate Change Impacts on Timber Markets, *Journal of Agricultural and Resource Economics* vol. 26 (2), pp. 326-343

Sohngen, B and Sedjo, R 2005, Impacts of climate change on forest product markets: Implications for North American producers, *Forestry Chronicle* vol. 81 (5), pp. 669-674

Soja, AJ, Tchebakova, NM, French, NHF, Flannigan, MD, Shugart, HH, Stocks, BJ, Sukhinin, AI, Parfenova, EI, Chapin, FS III and Stackhouse, PW Jr 2007, Climate-induced boreal forest change: Predictions versus current observations, *Global and Planetary Change* vol. 56, pp. 274-296

Sparks, TH and Menzel, A 2002, Observed changes in seasons: an overview, *International Journal of Climatology* vol. 22 (14), pp. 1715-1725

Staddon, C 2001, Local forest-dependence in postcommunist Bulgaria: A case study, *GeoJournal* vol. 54, pp. 517-528

Stedman, R, White, W, Petriquin, M and Watson, D 2007, Measuring Community Forest-Sector Dependence: Does Method Matter? *Society and Natural Resources* vol. 20, pp. 629-646

Stern, Nicholas. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press, online at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm. accessed 12 December 2007

Still, C, Foster, P and Schneider, SH 1999, Simulating the effects of climate change on tropical montane cloud forests, *Nature* vol. 398, pp. 608-610

Straussfogel, D 2006, Exploring the theoretical interface of climate change and resource dependency: application to the vulnerability of boreal forest regions, *Mitigation and Adaptation Strategies for Global Change* vol. 11, pp. 911-931

Sunderlin, WD, Angelsen, A, Belcher, B, Burgers, P, Nasi, R, Santoso, L and Wunder, S 2005, Livelihoods, forests, and conservation in developing countries: An Overview, *World Development* vol. 33 (9), pp. 1383-1402

Sunderlin, WD, Angelsen, A and Wunder, S 2003, Forests and Poverty Alleviation, in *State of the World's Forests 2003*, pp. 61-73, FAO, Rome

Swanson, CS and Loomis, JB 1996, *Role of non-market economic values in benefit-cost analysis of public forest management*, Portland (OR): USDA Forest Service, General Technical Report PNW-GTR-361

Swetnam, TW, Allen, CD and Betancourt, JL 1999, Applied historical ecology: using the past to mange for the future, *Ecological Applications* vol. 9 (4), pp. 1189-1206

Swetnam, TW and Betancourt, JL 1998, Mesoscale Disturbance and Ecological Response to Decadal Climatic Variability in the American Southwest, *Journal of Climate* vol. 11, pp. 3128-3147

Sykes, MT and Prentice, IC 1996, Climate change, tree species distributions and forest dynamics: A case study in the mixed conifer/northern hardwoods zone of Northern Europe, *Climatic Change* vol. 34, pp. 161-177

Tacconi, L 2007, Decentralization, forests and livelihoods: Theory and narrative, *Global Environmental Change* vol. 17, pp. 338-348

Taylor, AH and Beaty, RM 2005, Climatic influences on fire regimes in the northern Sierra Nevada mountains, Lake Tahoe Basin, Nevada, USA, *Journal of Biogeography* vol. 32, pp. 425-438

Tenow, O, Nilssen, AC, Holmgren, B and Elverum, F 1999, An insect (*Argyresthia retinella*, Lep., Yponomeutidae) outbreak in northern birch forests, released by climatic changes?, *Journal of Applied Ecology* vol. 36, pp 111-122

Thellbro, C 2006, *Local natural resource dependency in a Swedish boreal municipality*, Lic. Thesis, Dept. of Forest Resource Management and Geomatics, SLU. Rapport / Sveriges lantbruksuniversitet, Institutionen för skoglig resurshushållning och geomatik vol. 19

Theurillat, JP and Guisan, A 2001, Potential impact of climate change on vegetation in the European Alps: a review, *Climatic Change* vol. 50, pp. 77-109

Thomas, DSG and Twyman, C 2005, Equity and justice in climate change adaptation amongst natural-resource-dependent societies, *Global Environmental Change* vol. 15, pp. 115-124

Thompson, LG, Mosley-Thompson, E, Brecher, H, Davis, M, Leon, B, Les, D, Lin, PN, Mashiotta, T and Mountain, K 2006, Abrupt tropical climate change: Past and present, *Proceedings of the National Academy of Sciences* vol. 103 (28), pp. 10536-10543

Tilahun, M, Olschewski, R, Kleinn, C and Gebrehiwot, K 2007, Economic analysis of closing degraded *Boswellia papyrifera* dry forest from human interventions – A study from Tigray, Northern Ethiopia, *Forest Policy and Economics* vol. 9, pp. 996-1005

Tinner, W and Lotter, AF 2001, Central European vegetation response to abrupt climate change at 8.2 ka, *Geology* vol. 29 (6), pp. 551-554

Torn, M, Mills, E and Fried, J 1999, Will Climate Change Spark More Wildfire Damage? *Contingencies: Journal of the American Academy of Actuaries* July/August, pp. 34-43, online at http://eetd.lbl.gov/emills/PUBS/wild.html accessed 31 October 2007

Trieu, VH 2003, Forestry for poverty reduction in Viet Nam, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

TROFCCA 2005, *Natural Resources, Communities and Climate Change in West Africa: Impacts, Vulnerability and Responses*, draft, CIFOR Tropical Forests and Climate Change Adaptation Project

Truong, C, Palme, AE and Felber, F 2007, Recent invasion of the mountain birch Betula pubescens ssp. tortuosa above the treeline due to climate change: genetic and ecological study in northern Sweden, *Journal of Evolutionary Biology* vol. 20 (1), pp. 369-380

Tschakert, P 2007, Views from the vulnerable: Understanding climatic and other stressors in the Sahel, *Global Environmental Change* vol. 17, pp. 381-396

Tshering, D 2003, Forests for poverty alleviation: case of Bhutan, in *Forests for Poverty Reduction: Changing Role for Research, Development and Training Institutions*, Sim, HC, Appanah, S and Hooda, N (eds), FAO, Bangkok

Turner, NJ, Davidson-Hunt, IJ and O'Flaherty, M 2003, Living on the Edge: Ecological and Cultural Edges as Sources of Diversity for Social-Ecological Resilience, *Human Ecology* vol. 31 (3), pp. 439-461

UN Millennium Development Project 2005, *Environment and human well-being: a practical strategy*, United Nations Millennium Project Task Force on Environmental Sustainability, online at http://www.unmillenniumproject.org/reports/tf_environment.htm accessed 02 November 2007

USDA 2000, *The Impacts of Climate Change on America's Forests: a technical document supporting the 2000 USDA Forest Service RPA assessment*, Joyce, LA, Birdsey, R, Eds US Department of Agriculture Forest Service, Rocky Mountain Research Station.

Utescher, T and Mosbrugger, V 2007, Eocene vegetation patterns reconstructed from plant diversity – A global perspective, *Palaeogeography, Palaeoclimatology, Palaeoecolgy* vol. 247, pp. 243-271

van Kooten, GC 1995, Climatic-change and Canada boreal forest – Socioeconomic issues and implications for land-use, *Canadian Journal of Agricultural Economics* vol. 3, pp. 133-148

VEMAP Members 1995, Vegetation/Ecosystem Modeling and Analysis Project (VEMAP): Comparing Biogeography and Biochemistry Models in a Continental-Scale Study of Terrestrial Ecosystem Responses to Climate Change and CO_2 Doubling, *Global Biogeochemical Cycles* vol. 9 (4), pp. 407-437

Vincens, A, (and 12 others) 1999, Equatorial Africa during the last 4000 years BP and inheritance on the modern landscapes, *Journal of Biogeography* vol. 26, pp. 879-885

Vlassova, TK 2002, Human impacts on the tundra-taiga zone dynamics: The case of the Russian lesotundra, *Ambio Special Report 12*, pp. 30-36

Vlassova, TK 2006, Arctic residents' observations and human impact assessments in understanding environmental changes in boreal forests: Russian experience and circumpolar perspectives, *Mitigation and Adaptation Strategies for Global Change* vol. 11, pp. 897-909

Vogel, C, Moser, SC, Kasperson, RE and Dabelko, G 2007, Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships, *Global Environmental Change* vol. 17, pp. 349-364

Volney, WJA and Fleming, RA 2000, Climate change and impacts of boreal forest insects, *Agriculture, Ecosystems and Environment* vol. 82, pp. 283-294

Voronin, PY, Konovalov, PV, Bolondinskii, VK, Kaipiainen, IK and Mao, ZJ 2005, Delciline in the Primary Productivity of Northwestern European Forests as a Consequence of Climate Aridization. *Russian Journal of Plant Physiology* vol. 52 (4), pp. 454-458

Wall, G 1998, Implications of global climate change for tourism and recreation in wetland areas, *Climatic Change* vol. 40, pp. 371-389

Walther, GR 2003, Plants in a warmer world, *Perspectives in Plant Ecology, Evolution and Systematics* vol. 6, pp. 169-185

Walther, A and Linderholm, HW 2006, A comparison of growing season indices for the Greater Baltic Area, *International Journal of Biometeorology* vol. 51 (2), pp. 107-118

Warren, R, Arnell, N, Nicholls, R Levy, P and Price, J 2006, *Understanding the regional impacts of climate change Research Report Prepared for the Stern Review on the Economics of Climate Change*, Working Paper 90, Tyndall Centre for Climate Change Research, Norwich

WCMC 1999, *Forests in Flux. Climate Change: the Threats to World Forests*, United Nations Environment Programme-World Conservation Monitoring Centre. Draft online at http://www.unep-wcmc.org/forest/flux/ForestsinFlux.pdf accessed 17 October 2007

Wearne, LJ and Morgan LW 2001, Recent forest encroachment into subalpine grasslands near Mount Hotham, Victoria, Australia, *Arctic Antarctic Alpine Res.*, vol. 33. pp. 369-377

Wermelinger, B 2004, Ecology and management of the spruce bark beetle *Ips typographus*-a review of recent research, *Forest Ecology and Management* vol. 202, pp. 67-82

Whitlock, C, Shafer, S and Marlon, J 2003, The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosxstem management, *Forest Evology and Management* vol. 178, pp. 5-21

Williams, AAJ, Karoly, DJ and Tapper, N 2001, The sensitivity of Australian fire danger to climate change, *Climatic Change* vol. 49, pp. 171-191

Williams, DW and Liebhold, AM 2002, Climate change and the outbreak ranges of two North American bark beetles, *Agricultural and Forest Entomology* vol. 4, pp. 87-99

Williams, SE 2003, Biodiversity and climate change in the tropical montane rainforests of northern Australia, in *Global Climate Change and Biodiversity*, RE Green, M Hartley, L Miles, J Scharlemann, A Watson and O Watts (eds), Tyndall Center for Climate Change Research, Norwich

Williamson, TB, Price, DT, Beverly, JL, Bothwell, PM, Parkins, JR, Patriquin, MN, Pearce, CV, Stedman, RC and Volney, WJA 2007, *A framework for assessing the vulnerability of forest-based communities to climate change*, Information Report NOR-X-414, Northern Forestry Centre, Canadian Forest Service, Edmonton

Wilmking, M, Juday, GP, Barber, VA and Zald, HJS 2004, Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds, *Global Change Biology* vol. 10 (10), pp. 1724-1736

Wilson, CA and Mitchell, JFB 1987, A Doubled CO_2 Climate Sensitivity Experiment with a Global Climate Model Including a Simple Ocean, *Journal of Geophysical Research* vol. 92 (D11), pp. 13315-13343

Winnett, SM 1998, Potential effects of climate change on U.S. forests: a review, *Climate Research* vol. 11, pp. 39-49

Woodhead, A, Hyndman, D and Dunn, T 2004, Pratt Water: Timber Plantation Project Social Assessment, in *Feasibiliy of Timber Plantations in the Upper Murrumbidgee Catchment – a Triple Bottom Line Analysis. The Fifth Estate*, Pratt Water, Campbellfield

World Bank 2006, *India. Unlocking Opportunities for Forest-Dependant People in India*, Report No. 36481-IN, World Bank

Xaio, X, Melillo, JM, Kicklighter, DW, McGuire, AD, Prinn, RG, Wang, C, Stone, PH and Sokolov, A 1998, Transient Climate Change and Net Ecosystem Production on the Terrestrial Biosphere, *Global Biogeochem. Cycles*, vol. 12, pp. 345-360

Yin, CH, Yan, XD, Shi, ZG and Wang, ZM 2007, Simulation of the climatic effects of natural forcings during the pre-industrial era, *Chinese Science Bulletin* vol. 52 (11), pp.

Zheng, J, Ge, Q, Hao, Z and Wang, W 2006, Spring phenophases in recent decades over eastern China and its possible link to climate changes, *Climatic Change* vol. 77, pp. 449-462

Zhou, L, Tucker, CJ, Kaufmann, RK, Slayback, D, Shabanov, NV and Myneni, RB 2001, Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981–1999, *Journal of Geophysical Research* vol. 106, pp. 20069–20083

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