# Forest and social resilience to climate change

## A brief primer on ‘who is doing what’

**Duncan Macqueen**
**& Sonja Vermeulen**

iied

**International Institute for Environment and Development (IIED)**

## Contents



## Contacts

Duncan Macqueen
Senior researcher in Responsible Forest Business, Natural Resources Group
International Institute for Environment and Development (IIED)
4 Hanover Street, Edinburgh EH2 2EN
Tel: +44 131 226 6860; Fax: +44 131 624 7050
Email: duncan.macqueen@iied.org

Sonja Vermeulen
Senior Researcher, Natural Resources Group
International Institute for Environment and Development (IIED),
3 Endsleigh Street, London, WC1H 0DD
Tel: +44 207 872 7236; Fax: +44 207 388 2826
Email: sonja.vermeulen@iied.org

## A brief guide to 'who is doing what' on forest resilience to climate change.

## 1. Introduction

This revised guide is a brief primer for those interested in working on climate change and forest resilience. It focuses mainly on the prospects for adaptation by forest dependent people and their institutions. Our assumption is that the capacity of these institutions will determine how successful climate change adaptation is. For local institutions, access to information is an important first step in developing workable strategies – hence this primer. Building capacity on forest resilience and climate change in the South is a particular priority – partly because of the strong northern bias exhibited in the literature – and partly because it is in the South that climate change and forest dependence are more acute.

This brief primer is organised into five short sections as a series of questions:

- *Climate change*: What is the evidence for climate change and its likely impacts?
- *Forest resilience*: What are the main challenges to forest resilience resulting from climate change?
- *Livelihood challenges*: What are the main livelihood challenges to forest-dependent people due to climate change?
- *Adaptation strategies*: What are forest-dependent people doing to adapt to climate change?
- *Institutional capacity*: How can local institutions enhance their capacity to address climate change in the forestry context?

Each section contains details of 'who is doing what' on each issue, and what their main advice is. Organising the material in this way makes it easier for the reader to follow up what interest them. Where possible we have linked references directly to where they can be found on the internet.

## 2. Climate change: What is the evidence for climate change and its likely impacts?

In this section, we summarise some of the evidence for climate change and the effects it is likely to have – particularly in regard to the forest sector. There is now little doubt that climate change is a reality and that its impacts are being felt. It is also clear that poor people are both most dependent on natural resources, including forests, and most vulnerable to the impacts of climate change (Macqueen and Mayers, 2006). But what changes are predicted and where?

The Intergovernmental Panel on Climate Change (IPCC) (http://www.ipcc.ch/) was established as a global panel by WMO and UNEP to assess evidence for climate change. IPCC produced some landmark reports in 2001. These documented the evidence that climate change was happening, that a significant proportion of that change was man-made. They also predicted that over the next century the earths climate will change faster than in any period of history since the last ice age. (IPCC, 2001a). For example, by the end of the century there is predicted to be a rise in temperature between 1.4-5.8 °C and sea level rises between 0.09-0.88m. Extreme weather events will also increase.

The Tyndall Centre for Climate Change (http://www.tyndall.ac.uk/) is a UK based group. They produce a series of research reports on climate change. Some of which have suggested that climate change will not necessarily be slow and linear – once threshold points are reached change may be fast and potentially difficult to reverse (Hulme, 2003). And they have played a major role in predicting the regional impacts of climate change (Warren et al. 2006). For example:

- Water availability will generally increase in high latitude or wet tropics and decreases in low latitudes and dry tropics.
- Agriculture will generally decline in all areas except Europe, N. America and Australia with particular problems for maize dependent groups.
- Coastal flooding will have particularly serious consequences in South and South East Asia (and increasingly in Africa).
- Malaria, Dengue and Diarrhoea are likely to spread.
- Ecosystems such as coral reefs, arctic systems and tropical biodiversity hotspots are likely to suffer the highest extinction rates.
- Forest fires and pests will have increasingly serious consequences for forest-dependent people.

The Tyndall Centre has also produced some interesting specific assessments – such as an assessment of the fate of atolls (Barnett and Adger, 2001).

The Hadley Centre (http://www.met-office.gov.uk/research/hadleycentre/index.html) also puts out useful information on climate change and its impacts – including an overview of climate change and the greenhouse effect – a detailed introduction to the subject (Hadley Centre, 2005). This report presents evidence in changing concentrations of gases, other factors that affect the climate, and presents a review of current and likely future trends.

Journals – there at least a couple of journals that look at climate policy, some of which have articles on forest issues, For example Burton et al. (2002) in Climate Policy (http://www.earthscan.co.uk/defaultCLIMATE_POLICY.asp/). Nature has been an important player in the climate change literature (e.g. Walther et al. 2002; Root et al. 2003; Thomas et al. 2004). Other journals such as Climatic Change have a strong technical rather than policy bias – but can be consulted for detailed analysis of the evidence on which climate change theory is based.

Two weather institutions deserve mention here. The World Meteorology Organization (WMO) (http://www.wmo.ch/) publishes the WMO bulletin with interesting feature articles on issues such as storm risks, flooding and disaster prevention strategies. It also publishes the World Climate News that documents changes as they occur several times per year and a series of other technical weather orientated reports. The Tropical Meteorological Project (http://hurricane.atmos.colostate.edu/) has good data on Southern weather effects - the occurrence of tropical storms and hurricanes and the extent to which these can be linked to climate change. Although precipitation will increase, there is still doubt over whether wind intensities are being affected by climate change (Gray and Klotzbach, 2005)

## 3. Forest resilience: What are the main challenges to forest resilience resulting from climate change?

Climate change affects all sectors. Its impacts in the forest sector are likely to be particularly important, partly because trees have such long life spans, and must consequently be that much more resilient to long periods of incremental change. In part, it is because forests and trees on farm often comprise safety nets for livelihoods threatened by difficulties in agriculture (crop failure, livestock death etc). And in part, it is because forests and trees on farm are so extensive with so many claims (often around poorly defined tenure) – resulting in potential conflicts over their use. So what are the threats to forest resilience?

The Intergovernmental Panel on Climate Change (IPCC) (http://www.ipcc.ch/) has published data that support inevitably changes to ecosystems and biodiversity as a result of climate change (Gitay et al. 2002). In general forest species will move pole-ward and upward from their current locations. Increasing extreme weather events will affect forests through wind-throw, flooding, fires and an increased incidence of pests and disease. A 20% loss of coastal wetlands by 2080 due to sea level rises will have severe impacts on those communities. In general, diverse mosaics of land use that include biodiverse corridors of natural vegetation are likely to be more resilient than monocultures.

United Nations Environmental Programme (UNEP) (http://www.unep-wcmc.org/forest/flux/) and the World Conservation Monitoring Centre (WCMC) have been conducting a significant body of research on forests in flux (UNEP, 2005) and what impacts are likely to be on different forest types. For example:

- *Boreal forests* will experience the largest temperature increases especially in winter (4.0 °C above 1970s levels by the mid-21st century). Lower soil moisture in summer will increase drought-stress and the extent of wild fires. Climate zones will migrate northwards faster than many trees are able to migrate leading to some extinction.
- *Temperate forests* will be affected most at higher latitudes by climate warming (2.6 °C above 1970s levels by the mid-21st century) and at lower latitudes by changes in rainfall. Drought-stress at certain low-latitude margins will lead to significant dieback, whilst increased temperature will enhance growth and establishment of temperate forest species at higher latitudes. An overall expansion of potential temperate forest area is likely (by between 7% and 58%). The relatively high level of fragmentation of many temperate forests is likely to constrain migration patterns and lead to significant species losses during transition phases.
- *Tropical forests* are expected to warm by 2.0 °C above 1970s levels by the mid-21st century, with larger effects in continental interiors. However, changes in rainfall will be more important than changes in temperature. Reduced rainfall, higher temperatures and reductions in soil moisture will cause significant dieback and increase fire risk. Interannual variability in large-scale climate events such as El Niño may act to exacerbate these effects. Losses of forest cover in these biodiverse zones will cause significant species losses.

- *Tropical montane rain forests* are likely to warm by 1.0-2.0 °C, but are most threatened by changes in the height of the cloud base. Clouds base height may rise by up to 2.0 m yr-1, forcing species dependent on high atmospheric moisture to migrate upwards. Where mountains are isolated and of lower altitude than the changed height of the cloud base, outward migration of species will be impeded and climate change will lead to complete losses of many species, including many endemics (those found nowhere else).
- *Mangrove* forests will be able to adapt to rising temperatures, but may be threatened by rising sea levels. This threat will be particularly acute on sediment-poor coasts such as those found on small islands, and in areas where inland migration is constrained by human land use.

UNEP have also been working to standardise vulnerability assessment, primarily to allow donors to prioritise funding for adaptation (UNEP, 2001).

World Wide Fund For Nature (WWF) (http://www.worldwildlife.org/) have worked with Wageningen University to document evidence for change in response to extreme weather (Leemans and Van Vliet, 2004). The latter authors argue that impacts on ecosystems are more extreme than we might expect for the temperatures rises so far. Possible explanations include the fact that small changes in conditions may exceed threshold values for biological processes, or cause related effects that magnify impacts (such as fire), or stop highly evolved interactions between species that depend on careful temporal sequencing.

A team led by the School of Biology at the University of Leeds (http://www.leeds.ac.uk/media/current/extinction.htm) have shown that based on mid-range climate warming scenarios, scientists estimate that 15-37% of species may be 'committed to extinction' as the 'climate envelope' within which they can survive migrates or shrinks (Thomas et al., 2004). Loss of forest areas and species within those areas will both decrease ecosystem resilience and add to the release of carbon dioxide and global warming. Scientists from the University of Costa Rica say that these figures may be conservative – in part because of the complex ecological interactions noted by Leemans and Van Villet - that will be disrupted in unpredictable ways (Pounds and Puschendorf, 2004).

The CIFOR and CATIE project Tropical Forests and Climate Change Adaptation (TroFCCA) (http://www.cifor.cgiar.org/trofcca/_ref/home/index.htm) have just begun an extensive programme of research in West Africa, Asia and Central America to look at the impacts of climate change specifically on tropical forests. While it is too early yet for research results, the team have produced a very useful background paper for their three launch meetings (CIFOR, 2006). They define vulnerability in terms of the exposure of the forest system to climate change impacts, the sensitivity of the system and the adaptive capacity either natural or managed. The major processes affected by increasing carbon dioxide, temperature and changing rainfall include the following (slightly adapted):

- Changes in the location of areas suitable for particular species to grow
- Increases in the productivity of both timber and non-timber forest products (NTFPs)
- Changes in pest and disease outbreaks
- Altered ecosystem functions (biochemical cycles)
- Changing reproductive cycles
- Changing values of the forest for commercial use or recreation

The Royal Society of London (http://www.royalsociety.org/) – have sponsored significant work on climate change including some workshops on the theme – also with a particular focus on tropical forests. For example, they summarise how temperature related and carbon dioxide related changes affect competition – increasing rates of growth in tropical forests, changing soil acidity and placing new limits on nutrient uptake (Mahli and Philips, 2004). They have also drawn attention to the importance of Montane habitats as refugia (Mayle et al. 2004) – and the need to make sure these are regarded as protected areas.

Also in tropical forests, the Large-scale Biosphere-Atmosphere Experiment in Amazonia (LAB) (http://lba.cptec.inpe.br/lba/index.php?lg=eng) has been looking at the impact of climate change on the tropical forests of the Amazon basin. The El Niño-Southern Oscillation events of 1982-1983 and 1997-1998 and more recently in 2001 have led to significant droughts and fires across the region. This has increased the susceptibility to future fire events – which are themselves exacerbated by human activity such as logging and land conversion (Davidson and Artaxo, 2004).

Forest Research of the UK Forestry Commission (FC) (http://www.forestresearch.gov.uk/climatechange) have also been researching the multiple ways in which climate change will alter forests – primarily in the UK - through: temperature, carbon dioxide levels, wind strength, water supply and availability etc (Broadmeadow, 2005). Detailed analysis of the main climate change variables found a number of positive and negative effects for UK forests:

- *Higher atmospheric carbon dioxide – Beneficial effects:* Increase in growth rate; Reduction in stomatal conductance; Increased water use efficiency. – *Negative effects*: Increase in leaf area and thus higher wind resistance; Possible effects on ground vegetation; Reduction in timber quality; Possible nutrient imbalances.
- *Increasing ozone pollution – Beneficial effects:* None – *Negative effects:* Reduction in growth rate; Impaired stomatal regulation; Increased susceptibility to drought.
- *Higher temperature – Beneficial effects:* Longer growing season; Increased potential productivity; Lower risk of winter cold damage; Less snow damage; Potential use of species that are not hardy at present. – *Negative effects:* Delayed hardening; Risk of spring and autumn frost damage possibly increased; Longer growing season reducing winter soil water recharge period; Reduced winter mortality of insect and mammalian pests; More rapid development and increased fecundity of insect and mammal pest; Potential for exotic/alien pests to spread to the UK.
- *Increasing winter rainfall and summer droughts – Beneficial effects:* Reduced intensity of some foliar pathogens. – *Negative effects:* Winter water logging limiting access for forest operations; Reduced tree stability; Root death increasing susceptibility to drought and soil borne pathogens; Summer drought induced mortality.
- *Increased wind intensities – Beneficial effects:* None – *Negative effects:* Increased risk of wind damage;
- *Reduced overall cloud cover – Beneficial effects:* Increased potential productivity – *Negative effects:* Increased diurnal temperature range in autumn - increased risk of frost damage.

Together with various other independent researchers they have also been looking at how changing interactions between tree and diseases might evolve (Williams and Liebhold, 1995; 2002; Alig et al. 2004; Brasier, 2005). In general – stressed trees and better conditions for some pests and diseases are serious concerns.

The Pew Centre on Climate Change (http://www.pewclimate.org/) covers similar ground, but is very US orientated - compiling evidence about what causes climate change, what its impact might be on the US and how international policy initiatives are shaping up. For example, they have produced a detailed report on the likely impact of climate change on US forest resources (Shugart et al. 2004). Despite past forest adaptation to temperature changes of 2-3 °C - this took place over thousands of years and is not comparable to current rates of change. Increasing incidence of fire, pest outbreaks and wind-throw is expected - with serious economic consequences. But this will be offset by faster growth of existing or immigrant species. Adaptation through species selection is likely to enable a wealthy country such as the US to adapt.

USDA Forest Service and Global Change Programme Office (http://www.usda.gov/oce/gcpo/) together with Montana State University and others - have been looking at the interactions between climate change and biodiversity and forest composition (Hansen et al., 2001). Changes will differ for forests in different locations. Tree species survival will depend on their ability (and that of their pollinator and dispersal agents) to accommodate climate change or migrate to follow shifting climate zones. While such general comments can be made – precise predictions about the resilience of individual species have to be considered on a case-by-case basis.

The University of Maryland Centre for Environmental Science (http://www.al.umces.edu/faculty/) have been looking at climate change and plant migration. Because plant and animal species need to migrate to maintain climatic tolerance, the lack of continuous corridors along which to do so represents a significant problem (Pitleka, 1997). At a landscape level – maintaining forest corridors (particularly North-South or lowland-upland) is an important long-term strategy.

The University of Texas – Section on Integrative Biology (http://www.biosci.utexas.edu/IB/) has also been looking at the evidence for and impacts of climate change on terrestrial flora and fauna (Parmesan et al, 2000; Parmesan and Yohe, 2003). In studies of 1700 species they found supporting evidence for significant range shifts in plant species averaging 6.1 km per decade towards the poles (or metres per decade upward), and significant mean advancement of spring events by 2.3 days per decade. They concluded that the suite of analyses generates 'very high confidence' (as laid down by the IPCC) that climate change is already affecting living systems.

## 4. Livelihood challenges: What are the main livelihood challenges to forest-dependent people due to climate change?

The sections above demonstrate the magnitude of change that is likely to affect forest ecosystems. The impacts on the livelihoods of the forest dependent poor will vary depending on their type of dependence.

Some are land titled indigenous forest dwellers or small-scale farmers at the forest margin, relying on forests or trees on farm for food, construction material, fuel, fodder and medicines. Others are landless members of communities reliant on subsistence gathering of the same, or waged employment within local enterprise. Others are artisans, traders and small-scale entrepreneurs reliant on particular timber or non-timber forest products (NTFPs) for income generation. Yet others are urban or peri-urban groups reliant both on forest products (for shelter, fuel etc) and also the environmental services such as clean water originating in forest areas. What are the challenges to people's livelihoods and to local economies because of changing forest resilience?

The New Economics Foundation (NEF) (http://www.neweconomics.org/gen/climate_change_top.aspx) - have been doing research and advocacy on the likely impacts of climate change on people (NEF, 2002). Together with IIED (see below) NEF have had a particular recent focus on the livelihood impacts of climate change in the poorest countries. In a series of reports entitled 'Up in smoke', 'Africa - Up in Smoke' and 'Africa – up in smoke 2' they have highlighted major impacts of increasing temperatures and the unpredictability and intensity of drought events (Simms et al. 2004; Simms and Reid, 2005; Magrath and Simms, 2006). In general, forest-dependent people are likely to be affected by:

- Failure of natural resources due to increasing temperature and weather extremes and related disasters such as fires, drought, flood, pest outbreaks – leading to falling food security (e.g. loss of some forest foods)
- Increasing conflicts over water sources and available natural resources (e.g. access to livestock fodder in dry woodlands)
- Exacerbated desertification and resultant migration
- Weakened ability to cope due to the spread in disease
- Coastal and infrastructure vulnerability to rising seas levels and flood events.

While none of these challenges is unique to forestry, forest resources will come under increasing pressure as agricultural, freshwater and marine resources are threatened. Indigenous forest dwellers and small-scale farmers may encounter failure in either the agricultural or tree component of their systems and may have to adapt accordingly. Artisans, traders, small-scale entrepreneurs, and the landless poor dependent on them for work may encounter threats to the production of key timber of NTFP products. And the urban and peri-urban poor may be threatened by such effects as decreasing water supply or increasing forest product prices.

The International Institute for Environment and Development (IIED) (http://www.iied.org/climate_change/) has documented livelihood challenges for Sub-Saharan Africa, Asia and Island States (Huq et al. 2003). In addition to challenges based around water, food security and health Huq et al (2003) give specific attention to natural resource management and biodiversity (largely focusing on forest and tree resources). They note a series of challenges:

- Failures of some tree species – due to changing temperatures, rainfall and fires – and resultant land degradation
- Increased frequency and intensity of storm events in some small island states
- Pest and disease outbreaks such as locusts in Sub-Saharan Africa
- Coastal damage and inundation in countries such as Bangladesh
- Animal migration and increasing animal-human conflicts (e.g. Tigers from the flooded Sundarban forests)

The Food and Agriculture Organisation of the United Nations (FAO) (http://www.fao.org/clim/activities.htm) note that livelihood challenges also include issues relating to environmental services (and not just forest products – Robledo and Forner, 2005). They note challenges to do with:

- Watershed management – to cope with extreme or average increases in rainfall
- Forest conservation – to cope with rehabilitation and forest enrichment after fires or storms
- Carbon sequestration – contributing to climate change mitigation
- Biodiversity management – coping with loss of potential species of use to bio prospecting
- Soil protection – coping with rainfall extremes or drought events and desertification.

The Millennium Ecosystem Assessment (http://www.millenniumassessment.org/en/index.aspx) has reviewed the global scale of the multiple threats to ecosystems – including climate change (Reid et al. 2005). The report assesses human wellbeing (basic materials for a good life, health, good social relationships, security and freedom of choice and action) and the extent to which ecosystem services will continue to support wellbeing (through provisioning of food, water, fibre and fuel; by regulating climate water and disease; by strengthening the spiritual, aesthetic, recreation and educational components of culture; and by supporting primary production and soil formation). The report predicted that:

- By the end of the century, climate change and its impacts would be the dominant driver of biodiversity loss and changes in ecosystem services – and that by 2050:
- Habitat loss and other ecosystem changes are likely to result in a 10-15% loss of plant species
- Water withdrawals were projected to increase significantly in developing countries and there will be a deterioration in services provided by freshwater resources
- Food security will not be achieved and child malnutrition will not be eradicated despite increasing food supply and diverse diets
- Diseases will spread (for example excessive flooding and the warming of the great African Lakes may create conditions that increase the risk of Cholera)
- Cultural pluralism will come under increasing threat.

Each of these threats will have impacts on forest-dependent people in line with those discussed above.

In common with the Millennium Ecosystem Assessment the World Bank (http://lnweb18.worldbank.org/ESSD/envext.nsf/46ByDocName/KeyThemesVulnerabilityandAdaptationPovertyandClimateChange) has been stressing that vulnerability in terms of forest resources is only one element of much broader vulnerability involving broader ecosystem goods and services, food security, water, health, displacement and economic hardship (World Bank, 2003). In assessing the vulnerability of groups to climate change, they speak in terms of (Sperling and Szekely 2005):

- Changes in the magnitude of climatic extremes (e.g. heat waves, droughts, hurricanes etc)
- Changes in average climatic conditions and climate variability (e.g. average temperatures, rainfall levels, sea levels etc)
- Emerging threats (e.g. coral bleaching, spreading pests and disease, glacial melt water levels etc)

The distinction between disaster risk management and strategic adaptations in natural resource management is a useful one. The former category involves relatively unpredictable impacts – and the main challenge for local livelihoods will be post-disaster recovery. The second category involves incremental and more predictable challenges that can be studied and addressed through adaptation by local institutions. The final category is essentially a basket of unknowns – where challenges will have to be met as they arise through strong local institutions.

The University of East Anglia Climate Research Unit (http://www.cru.uea.ac.uk/) published a detailed study of climate change in Africa and its implications for livelihoods (Hulme, 1996). The analysis concluded that the main priority areas included:

- Securing sustainable water supply and quality
- Preventing and reversing desertification
- Combating coastal erosion and pollution
- Making efficient use of energy resources
- Managing forests and wildlife resources
- Managing demographic changes (e.g. climate migration)
- Securing adequate food security

While these areas go well beyond the forest sector – it can be seen how forest resources could potentially play a major role in addressing the livelihood challenges faced by forest-dependent people. Forest ecosystems can maintain water quality (although trees next to water course often increase water loss rather than decrease it). Trees have regularly been used to combat desertification. Mangrove forests play a vital role in coastal defences. Fuel-wood and charcoal are still a mainstay of energy production in many developing countries. Similarly, tree-based subsistence foods and fodders are often critical in times of drought.

## 5. Adaptation strategies: What are forest-dependent people doing to adapt to climate change?

In the face of climate-related disasters or more incremental changes in forest resilience, local people must adapt or perish. Adaptation means ‘adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts’. Climate change has already occurred – and people have already adapted. What strategies can and do people use to tackle these livelihood challenges? What new strategies might help in the future?

The Tyndall Centre for Climate Change (http://www.tyndall.ac.uk/) has undertaken specific work on adaptation strategies in Africa (Thomas et al. 2005). For example, they have documented changes:

- to existing natural resource practices (investing in storage, building livestock shelters, grinding maize as animal feed, buying salt, going to town to buy more seed etc)

- to the types of natural resources used in different areas (diversifying, changing vegetable or maize type, eating wild fruits, cutting fodder from trees, using short maturing crops or more resistant fruit trees, relocating small-stock to river areas),
- to reliance on commercialization or off-farm work (selling livestock, look for piece work, moving to town to find work, grouping together to start a business, starting gardening projects)
- to greater reliance on support networks and local institutions (convening village meetings or farming associations – to formalise reciprocity relationships, sending representatives to government authorities for help, going to church, relying more heavily on family networks).

The authors distinguish between coping (a transient response) and adaptation (longer terms strategies for survival). The adaptations in question are primarily those associated indigenous forest dwellers or small-scale farmers, often using natural forest resources or trees on farm. But what of the adaptations for artisan, traders and small-scale entrepreneurs who rely on commercial timber or NTFP harvesting or tree plantations?

Oak Ridge National Laboratory (http://www.esd.ornl.gov/) in the USA has been looking at the effect of climatic disturbance events on plantation forests and semi-natural woodlands (albeit in the US). They have been characterising the frequency, intensity and duration of forest disturbance such as fire, drought, introduced species, insect and pathogen outbreak, hurricanes and windstorms (Dale et al. 2001). They have also been documenting adaptive responses, for example:

- Managing the system before climatic disturbance: planting on less exposed or risky sites; planting more resistant species, extracting dead wood to avoid fires.
- Managing the disturbance: introducing fire precautions; implementing rapid response to fires and pests and diseases; preparing for post-disturbance extraction and use.
- Managing recovery: introducing structural diversity and age classes; preparing to replant more suitable species at more appropriate densities.
- Monitoring for adaptive management: developing a system of monitoring the state of the forests, fires and pests and disease outbreaks; linking disturbances with particular climatic or seasonal probabilities.

The International Union for the Conservation of Nature (IUCN) (http://www.iucn.org/themes/fcp/experience_lessons/climate_iucn_initiative.htm) – have been producing good introductory materials on the specific changes that will happen in forests (Willott and Thomas, 2001). They have also established a Task Force on Climate Change, Adaptation and Vulnerable Communities (Abramovitz et al., 2002; Orlando, 2003). They too divide adaptation into (i) disaster risk management and (ii) strategic adaptations in natural resource management. For disaster risk management they outline several categories of tool (Abramovitz et al, 2002) that broadly follow the Oak Ridge Laboratory headings above:

- Mitigation – activities to prevent or reduce impacts of a catastrophic event before it happens (such as public education or better land use planning and design such as building in fire breaks, planting more tolerant species etc.
- Preparedness – activities to improve the effectiveness of response (such as forest disease warning systems, fire fighting plans, storage of emergency foods or other raw materials)
- Response – activities during the acute phase of the disaster that save lives and restore basic services (such as flood or drought evacuation plans and disaster relief camps)
- Recovery – activities that restore capital (such as replanting programmes, repair to infrastructure etc)

These tools for disaster risk management are complemented by a series of tools to adapt natural resource management to changing conditions:

- Soil management – building in greater resilience to productive tree-based systems through fallow cycling, forest buffering, selective planting of nitrogen fixing trees, managed grazing, fire protection etc
- Water harvesting – building earthen dams, V-shaped planting plots, rooftop collection systems etc.
- Windbreak construction to reduce evaporation – building ridges, rock bunds, planting lines of resistant indigenous trees etc
- Diversification – intercropping selected food crops with trees, planting multiple types of resistant crops, planting early maturing varieties etc.
- Managing conflicts over common property resources – developing strategies to accommodate sedentary agriculturalists and migrant pastoralists.

The International Institute for Environment and Development (IIED) (http://www.iied.org/climate_change/) – are participating in both Northern and Southern NGO alliances looking primarily at how poor people might adapt to climate change – including the forest dependent poor. The hundreds of millions who rely on forest resources for shelter, energy, food, fodder, green manure, medicines and income are vulnerable to changes in those resources (Huq et al. 2003; Simms and Reid 2004; Reid, 2004). The production of Tiempo

magazine has also covered specific issues such as the impacts on mangroves and mangrove communities (Hong, 1993). In outlining the main strategies for adaptation, IIED focused on two least developed countries, Bangladesh and Mali. For Bangladesh, the main area of agreed adaptation in the forest sector was related to the Sundarbans mangrove forests – likely to be hit by increased salinity due to low dry season flows. In Mali, increasing temperatures and decreasing rainfall are the main threats to dryland forest and agriculture. Here, water conservation measures were to be complemented by the use of more resistant crops and the exploration of alternative livestock fodder species.

The International Institute for Sustainable Development (IISD) (http://www.iisd.org/climate/) have been looking at prescriptions about how adaptation might be fostered: responding to the needs of the poorest and most vulnerable groups, reducing the risks of disasters and managing the environment to maintain diversity (IISD, 2003a; 2003b; 2004). Among the lessons learned on climate change adaptation were the following set of basic requirements:

- A thorough understanding of local livelihoods and vulnerabilities
- A strong understanding of the main climate risks in the region and how they affect livelihoods (e.g. specific information of forest related changes)
- Community driven implementation at all stages of adaptation (initiation, design, implementation and monitoring)
- Community organisation – building on self help groups, women's groups and other local institutions
- Strong participation of women – recognising their role as household and community resource managers
- Local training and capacity building in a range of institutional skills such as technical financial and managerial skills.
- Blending traditional and modern approaches
- Reconciling short term interests (e.g. disaster risk management) from long term goals (strategic adaptation)
- A supportive policy environment (e.g. not forgetting to involve policy and decision makers and get the macro-frameworks right).

The Resilience Alliance (http://www.resalliance.org/ev_en.php) are a group of research organisations who have introduced the new discipline of panarchy to cope with complexity and multiple levels that will be required for adaptation to climate change (Gunderson and Holling, 2002; see also Holling, 1973). They note that to get the full picture for say a single tree species you also need to consider changes to predators, grazers, pollinators, nitrogen fixers, decomposers, dispersal agents, water users, creators of patches and colonisers of those gaps (Folke et al. 2002).

World Wide Fund For Nature (WWF) (http://www.worldwildlife.org/) have produced a manual on how to support the adaptation of forests to climate change (Hansen et al. 2003). For example, we might expect increases in disturbance, movement geographically and attitudinally, simplification of ecosystems – due to migration weeding out slow migrators, age reduction and extinction. They have been working with the ECE trade network to raise awareness of the impacts of climate change on forests and how to adapt (Rakonczay, 2003) In terms of forests – adaptation strategies might mean:

- Avoid fragmentation and promote connectivity
- Maximise size of management units
- Favour biodiversity – for discussion on biodiversity see IPCC, 2002
- Provide buffer zones
- Preserve forest types across habitat gradients
- Protect mature standards (that are more robust)
- Protect refugia (e.g. montane areas or traditional moist Amazonian refugia)
- Manage fire
- Manage pests
- Avoid monocultures

Use ex situ conservation for threatened species

Canadian Forest Service and Ministry of Forests (http://www.nrcan-rncan.gc.ca/cfs-scf/science/resrch/climatechange_e.html) have been looking at particular strategies for adaptation in Canada (e.g. Spittlehouse and Stewart, 2003). It is likely that vulnerable groups will be more concerned over the failure of particular forest species than with shifts in the forest ecosystem per se.

Similarly, the Forest Research of the UK Forestry Commission (FC) (http://www.forestresearch.gov.uk/climatechange) have provided detailed guidance on how to adapt. For people dependent on commercial woodlands, the advice has been to source seed material from latitudes

that are more southerly or more tolerant species. With commercial species taking at least 30 years to grow in most cases – seed collectors have tried to collect from current areas (e.g. southern France) that will match the UK in 30 years time. There are some options that are always recommended ('no regret options'):

- Species mixtures will provide some insurance against climate change - not all will be affected to the same extent.
- Provenance mixtures will provide insurance.
- Tree species and woodland types should be well matched to site; if currently at the dry end of their suitable range, they should not be planted.
- Climate change predictions should be considered in the choice of planting stock.
- At a landscape level, larger, better-connected woodland should be an objective.

Task force on Climate Change – International Chamber of Commerce (ICC) (http://www.iccwbo.org/home/environment_and_energy/sdcharter/topics/climate/joint.asp) looks at the need for business to adapt and how to shape negotiations governing this.

## 6. Institutional capacity: How can local institutions enhance their capacity to address climate change in the forestry context?

Adaptive capacity involves institutional ability to adjust to climate change, moderate potential damages and take advantage of opportunities or cope with new consequences. Considering the array of challenges and opportunities, what are the main ways in which local institutions could build their own capacity and resilience to adapt to climate change in the forestry context?

The Environmental Advisory Council to the Swedish government produced a significant paper for the World Summit on Sustainable Development (WSSD) on the challenge of getting social and economic policies and institutions (including markets) to change to make adaptation possible. Natural and social systems behave in non-linear ways, exhibit marked thresholds in their dynamics and are closely integrated with one another (Folke et al, 2002). Adaptation for humans might involve:

- Prioritise the vulnerable
- Prepare flexible iterative, policies and institutions
- Identify thresholds and early warning indicators
- Increase or maintain diversity
- Combine knowledge systems
- Create opportunities for self organisation

The central point is that adaptation will require strong local institutions – both to monitor climate change and impact trends and to develop bottom-up solutions that work in diverse areas coping with diverse problems.

The International Institute for Environment and Development (IIED) (http://www.iied.org/climate_change/) echoes this strong focus on strengthening the capacity of local institutions in the face of climate change (Reid, 2005). In introducing the nature of adaptation to climate change Huq et al. (2003) highlighted the difference between:

- Passive spontaneous response and active planned interventions
- Reactive approaches and proactive approaches
- Short-term responses and long-term strategic options
- Localised tactics and widespread preparedness

Lessons from Sub-Saharan Africa, Asia and small island states led to recommendations focusing initially on:

- Translating scientific data on climate change into simple policy messages for decision-makers and broader civil society
- Improved capacity for local research on the impacts of climate change – especially for the most vulnerable groups and areas
- Involving all sectors of society in long term programmes for capacity building towards national climate change adaptation

The Food and Agriculture Organisation of the United Nations (FAO) (http://www.fao.org/clim/activities.htm) view forest sector adaptation to climate change as a continuous process (Robledo and Forner, 2005). They stress the need to look broadly at timber, fuel and NTFP livelihoods in assessing vulnerabilities. There is a cycle involving three main components:

- Vulnerability assessment
- Implementation of adaptive measures
- Training and training needs evaluation

Capacity building in FAO terms involves among other things: ‘encouraging an institutional framework that promotes adaptation’ ‘guaranteeing conditions for adaptation at the local level’ and ‘promoting the development of human capacity for the encouragement, planning and implementation of adaptive measures in the forest sector’. Robledo and Forner (2005) note that it is important to consider the role of local communities because they ultimately implement measures at the local level.

The International Institute for Sustainable Development (IISD) (http://www.iisd.org/climate/) provide a framework for climate change adaptation (IISD, 2003). They introduce the current regime of adaptation agreed at COP 1 in Berlin 1995 – that included:

- *Stage 1* - planning studies of climate change impacts, vulnerable regions or groups and options for adaptation
- *Stage 2* – measures to prepare for adaptation (including capacity building)
- *Stage 3* – measures to facilitate adequate adaptation, including insurance.

IISD go on to observe that real adaptation is rarely top-down or orchestrated – it is more usually a continuous process run by local institutions. They recommend greater attention to:

- Understanding vulnerability-livelihood interactions
- Establishing the legal, policy and institutional framework gives appropriate authority at the level where that authority can best be used
- Developing a climate change adaptation strategy – including the financial means and institutional changes necessary to allow that to happen.

In the African study by the Tyndall Centre for Climate Change (http://www.tyndall.ac.uk/), specific mention is given of the role of informal village institutions and informal networks outside the village (Roberts et al. 2005). Sustained collective adaptation to climate change required:

- Inclusive local institutions that were established to increase equity at village level (so as not to create internal jealousies)
- Permitting structures to evolve that increase communication at village level (successful adaptation often involves those have been exposed to external networks or migrant work where new ideas or practices were observed)
- Evolving structures that facilitate further self-organisation – all four main areas of adaptation depended heavily on local institutions to spread good practice (natural resource management changes and skills, social networks, commercialisation and off-farm roles)
- Permitting the regular use of these institutional structures and networks to help plan for the future
- Facilitating livelihood specialisation – new resilient cash crops, off-farm labour etc.

There is a general lack of information on forest specific adaptations to climate change and the institutional structures that do or do not work in bringing that adaptation about. This major gap could provide the basis for a collaborative approach between parties interested in strengthening local forest institutions in the face of climate change.

## Annex 1. Some additional information on links between forests and climate change (including carbon sequestration)

The Food and Agriculture Organisation of the United Nations (FAO) (http://www.fao.org/clim/activities.htm) have assembled some information on official linkages between forestry and climate change mitigation – and the responses of member states to this

The Tyndall Centre (http://www.tyndall.ac.uk/) has also produced useful technical summaries- for example, of how afforestation and reforestation have been negotiated at the Conference of Parties meetings (Boyd et al. 2004).

Edinburgh Centre for Carbon Management (ECCM) (http://www.eccm.uk.com/home/links.html) are particularly strong in looking at the carbon sequestration potential of forests and forest products.

Global Change and the Terrestrial Ecosystem GCTE (http://www.gcte.org/index.htm) - and other research groups have been looking at how mature forests act as sinks and whether these sinks will saturate (Canadell, 1999; Cramer and Canadell, 1999) see also (Pregitzer and Euskirchen, 2004 and Paw U et al., 2004)

## Bibliography


Abramovitz J., Girot, P.O., Orlando, B., Schneider, N., Spanger-Siegfried, E., Switzer, J. and Hammill, A. (2002) Adapting to Climate Change: Natural Resource Management and Vulnerability Reduction, A Background Paper to the Task Force on Climate Change, Adaptation and Vulnerable Communities**.** Available at <http://www.iucn.org/themes/climate/docs/tfbackgourndpaper.pdf> [Cited May 2005]

Alig, R. Adams, D., Joyce, L. and Sohngen, B. (2004) Climate change impacts and adaptation in forestry: responses by trees and markets. Choices 2004. Fall issue. Available at: <http://www.choicesmagazine.org/2004-3/climate/2004-3-07.htm> [Cited May 2005]

Barnett, J. and Adgers, N. (2001) Climate dangers and atoll countries. Tyndall Centre for Climate Change Research Working Paper No. 9. Available at: <http://www.tyndall.ac.uk/publications/working_papers/wp9.pdf> [Cited May 2005].

Boyd E., Corbera E., Gutierrez M, Estrada M, (2004) The politics of afforestation and reforestation activities at COP-9 and SB-20: Tyndall Briefing Note 12 Available at: <http://www.tyndall.ac.uk/publications/briefing_notes/note12.pdf> [Cited November 2006]

Brasier, C. (2005) Climate change and tree health. Presentation to the UK conference on “Trees in a changing climate” held in the University of Surrey, 14-15 June 2005.

Broadmeadow, M.S.J., Ray, D. and Samuel, C.J.A. (2005) Climate change and the future for broadleaved tree species in Britain. *Forestry* 78 (2): 145-161.

Burton, I., Huq, S., Lim, B., Pilifosova, O. and Schipper, E.L. (2002) From impacts assessment to adaptation priorities: the shaping of adaptation policy. Climate policy 2 (2-3) 145-159.

Canadell, J. (1999) Will the terrestrial carbon sink saturate? GCTE research highlights No. 4. Available at: <http://www.gcte.org/ccarticle.htm> [Cited May 2005]

CIFOR (2006) An introduction to the impacts of climate change and vulnerability of forests. Available at <http://www.cifor.cgiar.org/trofcca/asia/docs/BP02-ImpactCC2forest.PDF> [Cited November 2006]

Cramer, W. and Canadell, J. (1999) Future trajectories of global terrestrial carbon fluxes. Available at: <http://www.gcte.org/cramer-Canadell.htm> [Cited May 2005]

Dale, V.H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, A.E., Peterson, C.J., Simberloff, D., Swanson, F.J., Stocks, B.J. and Wotton, M. (2001) Climate change and forest disturbances. Bioscience 51 (9): 723-734. Available at: <http://www.fs.fed.us/pnw/corvallis/mdr/mapss/bio-dale.pdf> [Cited May 2005]

Davidson, E.A. and Artaxo, P. (2004) Globally significant changes in the biological processes of the Amazon basin: results of the Large-scale Biosphere-Atmosphere Experiment. Global change biology 10: 519-529.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., Bengtsson, J., Berkes, F., Colding, J., Danell, K., Falkenmark, M., Gordon, L., Kasperson, R., Kautsky, N., Kinzig, A., Levin, S., Mäler, K-G., Moberg, F., Ohlsson, L., Olsson, P., Ostrom, E., Reid, W., Rockström, J., Savenije, H. and Svedin, U. (2002) Resilience and sustainable development: building capacity in a world of transformations. Scientific background paper for the process of The World Summit on Sustainable Development on behalf of the Environmental Advisory Council to the Swedish government. Available at: <http://resalliance.org/ev_en.php?ID=1498_201&ID2=DO_TOPIC> [Cited May 2005]

Gitay, H., A. Suárez, D. J. Dokken and R. T. Watson (2002) Climate Change and Biodiversity. Intergovernmental Panel on Climate Change Technical Paper V.

Gray, W.M. and Klotzbach P.J. Extended range forecast of Atlantic seasonal hurricane activity and US landfall strike probability for 2005. Available at: <http://hurricane.atmos.colostate.edu/Forecasts/2005/april2005/> [Cited May 2005]

Gunderson, L.H. and Holling, C.S. (2002) Panarchy. Understanding transformations in human and natural systems. Island Press, Washington D.C., USA.

Hadley Centre (2005) Climate Change and the Greenhouse Effect. A briefing from the Hadley Centre. Available at: <http://www.met-office.gov.uk/research/hadleycentre/pubs/brochures/2005/climate_greenhouse.pdf> [Cited November 2006]

Hansen, A.J., Neilson, R.P., Dale, V., Flather, C., Iverson, L., Currie, D.J., Shafer, S., Cook, R., and Bartlein, P. (2001). Global Change in Forests: Interactions among Biodiversity, Climate, and Land Use. BioScience 51(9):765-779. Available at: <http://www.homepage.montana.edu/~hansen/documents/downloadables/globchg.pdf> [Cited May 2005]

Hansen, L.J., Biringer, J.L. and Hoffman, J.R. Eds. (2003) Buying time: a user's manual for building resistance and resilience to climate change in natural systems. WWF Climate Change Programme. Available at: <http://www.worldwildlife.org/forests/pubs/buyingtime_unfe.pdf> [Cited May 2005]

Holling, C.S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4:1-23.

Hong, P.N. (1993) Climate and the mangrove ecosystem. Tiempo 10. Available at: <http://www.cru.uea.ac.uk/cru/tiempo/issue10/mangrove.htm> [Cited May 2005]

Hulme, M. (1996) Climate change and Southern Africa: an exploration of some potential impacts and implications in the SADC region. University of East Anglia. Summary available at: <http://www.cru.uea.ac.uk/~mikeh/research/cc_safr.htm> [Cited November, 2006]

Hulme, M. (2003) Abrupt climate change: can society cope? Tyndall Centre for Climate Change Research Working Paper No. 30. Available at: <http://www.tyndall.ac.uk/publications/working_papers/wp30.pdf> [Cited May 2005].

Huq, S., Rahman, A., Konate, M., Sokona, Y. and Reid, H. (2003) Mainstreaming Adaptation to Climate Change in Least Developed Countries (LDCs). IIED, London. Available at: <http://www.poptel.org.uk/iied/docs/climate/main_ldc_rprt.pdf> [Cited November 2006]

IISD (2003a) Livelihoods and climate change. Combining disaster risk reduction, natural resource management and climate change adaptation in a new approach to the reduction of vulnerability and poverty. IISD, Winnipeg, Canada. Available at: <http://www.iisd.org/pdf/2003/natres_livelihoods_cc.pdf> [Cited November 2006]

IISD (2003b) Coping with global change – vulnerability and adaptation in Indian agriculture. IISD, Winnipeg, Canada. Available at: <http://www.iisd.org/pdf/2004/climate_coping_global_change.pdf> [Cited November 2006]

IISD (2004) Sustainable livelihoods and climate change adaptation. IUCN and IISD, Winnipeg, Canada. Available at: <http://www.iisd.org/pdf/2004/envsec_sustainable_livelihoods.pdf> [Cited November 2006]

IPCC (2001a) Climate change 2001: The scientific basis. Contribution of working group 1 to the third assessment report of the Intergovernmental Panel on Climate Change. [Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A. (Eds.)]. Cambridge University press, Cambridge, UK. Available at <http://www.grida.no/climate/ipcc_tar/wg1/index.htm> [Cited May 2005]

IPCC (2001b) Climate change 2001: impacts, adaptation and vulnerability. Contribution of working group 2 to the third assessment report of the Intergovernmental Panel on climate Change. [McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (Eds.)] Cambridge University Press, Cambridge, UK. Available at <http://www.grida.no/climate/ipcc_tar/wg1/index.htm> [Cited May 2005]

IPCC (2002) Climate change and biodiversity. Intergovernmental Panel on Climate Change Technical Paper V. Available at: <http://www.ipcc.ch/pub/tpbiodiv.pdf> [Cited May 2005]

Leemans, R. and Van Vliet, A. (2004) Extreme weather: does nature keep up. Wageningen University, The Netherlands. Available at: <http://worldwildlife.org/climate/pubs.cfm> [Cited November 2006]

Macqueen, D.J. and Mayers, J. (Eds) (2006) Environmental governance: implications for donors from the practice of governance in agriculture, forestry and urban development. IIED, London, UK.

Magrath, J. and Simms, A. (2006) Africa – up in smoke 2. Available at: <http://www.neweconomics.org/gen/uploads/lkytv3555qtqge55lmyvnw4528102006182917.pdf> [Cited November 2006]

Mahli, Y. and Phillips, O.L. (2004) Tropical forests and global atmospheric change: a synthesis. *Philosophical Transactions of the Royal Society of London* 359: 549-555.

Mayle, F.E., Beerling, D.J., Gosling, W.D. and Bush, M.B. (2004) Responses of Amazonian ecosystems to climatic and atmospheric carbon dioxide changes since the last glacial maximum. *Philosophical Transactions of the Royal Society of London* 359: 499-514.

NEF (2002) The end of development? Global warming, disasters and the great reversal of human progress. New Economics Foundation, London, UK.

Orlando, B. (2003) Climate change and nature. Available at: <http://www.iucn.org/themes/climate/docs/climateandnature.pdf> [Cited May 2005]

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

Parmesan C. and Yohe, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421: 37–42.

Paw U, K.T., Falk, M., Suchanek, T.H., Ustin, S.L., Chen, J., Park, Y-S., Winner, W.E., Thomas, S.C., Hsiao, T.C., Shaw, R.H., King, T.S., Pyles, R.D., Schroeder, M. and Matista, A.A. (2004) Carbon dioxide exchange between an old growth forest and the atmosphere. Ecosystems 7: 513-524.

Pitleka, L.F. (1997) Plant migration and climate change. American scientist 85 (5): 464-474

Pounds, J.A. and Puschendorf, R. (2004) Ecology: clouded futures. *Nature* 427: 107-109.

Pregitzer, K.S. and Euskirchen, E.S. (2004) Carbon cycling and storage in world forests: biome patterns related to forest age. *Global change biology* 10: 2052-2077.

Rakonczay, Z. (2003) Managing forest for adaptation to climate change. Available at: <http://www.unece.org/trade/timber/docs/sem-1/papers/r8Rakonczay.pdf> [Cited May 2005]

Reid, H. (2004) 'Climate change – biodiversity and livelihood impacts' In D. Roe (ed.) The Millennium Development Goals and Conservation. IIED, London. Pp. 37-54. Available at: <http://www.iied.org/Gov/mdgs/documents/MDG2-ch3.pdf> [Cited November 2006]

Reid, H. (2005) Africa a crucible for climate change and poverty. Pp 157-174 in Bigg, T. and Satterthwaite, D. (Eds) How to make poverty history – the central role of local organisations in meeting the MDGs. IIED, London, UK. Available at: <http://www.iied.org/pubs/pdf/full/11000IIED.pdf> [Cited November, 2006]

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P, Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, T.A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, M.B. (2005) Ecosystems and human wellbeing. Synthesis - A report of the Millenium Ecosystem Assessment. Island Press, Washington D.C., USA. Available at: <http://www.millenniumassessment.org/en/products.aspx> [ Cited June 2005]

Robledo, C. and Forner, C. (2005) Adaptation of forest ecosystems and the forest sector to climate change. FAO, Rome, Italy. Available at: <www.inter**c**ooperation.**c**h/offers/download/Tropi**c**al**Forest**sAnd**Adaptation**To**ClimateChange**.pdf> [Cited November 2006]

Root T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig and J. A. Pounds (2003) 'Fingerprints of global warming on wild animals and plants' Nature 421: 57-60.

Rosenbaum, K.L., Schoene, D. and Mekouar, A. (2004) Climate change and the forest sector – possible national and subnational legislation. FAO Forestry Paper 144, FAO, Rome, Italy.

Shugart, H., Sedjo, R. and Sohngen, B. (2003) Forest and global climate change – potential impacts on US forest resources. Pew Centre for Climate Change. Available at: <http://www.pewclimate.org/docUploads/forestry%2Epdf> [Cited November 2006]

Simms, A., Magrath, J. and Reid, H. (2004) Up in Smoke. Available at: <http://www.neweconomics.org/gen/uploads/igeebque0l3nvy455whn42vs19102004202736.pdf> [Cited November, 2006]

Simms, A. and Reid, H. (2005) Africa – up in smoke. Available at: <http://www.neweconomics.org/gen/uploads/4jgqh545jc4sk055soffcq4519062005184642.pdf> [Cited November 2006]

Sperling F. and Szekely F. (2005) Diaster risk management in a changing climate. World Bank discussion paper. Available at: <http://siteresources.worldbank.org/INTCC/214574-1110866984338/20790846/Disaster_risk_management.pdf> [Cited November 2006]

Spittlehouse, D.L. and Stewart, R.B. (2003) Adaptation to climate change in forest management. British Columbia Journal of Ecosystems and Management 4 (1) 1-11. Available at: <http://www.forrex.org/jem/2003/vol4/no1/art1.pdf> [Cited May 2005].

Thomas C., Osbahr H, Twyman C, Adger W. N., Hewitson B, (2005) ADAPTIVE: adaptations to climate change amongst natural resource-dependant societies in the developing world: across the Southern African climate gradient. Tyndall Centre Technical Report 35 Available at: <http://www.tyndall.ac.uk/research/theme3/final_reports/t2_31.pdf> [Cited November 2006]

Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., Ferreira de Siqueira, M., Grainger, A. Hannah, L., Hughes, L., Huntley, B., Van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega,-Huerta, M.A., Peterson, A.T., Phillips, O.L. and Williams, S.E. (2004) Extinction risk from climate change. *Nature* 427: 145-148. Available at: <http://www.fishclimate.ca/pdf/Extinction_risk_from_climate_change_Nature_2004.pdf> [Cited November 2006]

UNEP (2001) Vulnerability indices. Climate change impacts and adaptation. United Nations Environment Programme, Nairobi, Kenya.

UNEP (2005) Forests in flux. Executive summary of a forthcoming report: Climate change: the threat to world forests. Available at <http://www.unep-wcmc.org/forests/flux/executive_summary.htm> [Cited May 2005]

Walther, G-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T., Fromentin, J-M., Hoegh-Guldberg, O. and Bairlain, F. (2002) 'Ecological responses to recent climate change' Nature 416: 389-395.

Warren R., Arnell N. W., Nicholls R., Levy P E, Price J, (2006) Understanding the regional impacts of climate change: Research Report Prepared for the Stern Review on the Economics of Climate Change. : Tyndall Working Paper 90. Available at: <http://www.tyndall.ac.uk/publications/working_papers/twp90.pdf> [Cited November 2006]

Williams, D.W. and Liebhold, A.M. (1995) Herbivorous insects and global change: potential changes in the spatial distribution of forest defoliator outbreaks. Journal of biogeography 22: 665-671.

Williams, D.W. and Liebhold, A.M. (2002) Climate change and the outbreak ranges of two North American bark beetles. Agricultural and Forest Entomology 4: 87-100. Available at: <http://www.sandyliebhold.com/pubs/williamsandliebhold_barkbeetle.pdf> [Cited May 2005]

Willott, J. and Thomas, C. (2001) Implications of climate change for species conservation. Briefing paper for an IUCN workshop in Gland 19-21 February 2001. Available at: <http://www.iucn.org/themes/climate/docs/ccspeciessurvival.pdf> [Cited May 2005]

World Bank (2003) Poverty and climate change. Reducing the vulnerability of the poor through adaptation. World Bank, Washington, USA. Available at: <http://lnweb18.worldbank.org/ESSD/envext.nsf/46ByDocName/KeyThemesVulnerabilityandAdaptationPovertyandClimateChange> [Cited May 2005]