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ADAPTING TO CLIMATE CHANGE

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Adapting to climate change

Evidence that the cumulative effects of human activities are changing the world's climate has become all but irrefutable. What will it mean for the world's forests? Grim threat or opportunity for growth? In the absence of certainty, it depends on the point of view.

The question of how forests and forest-dependent people will adapt to climate change is a growing area of research and has been at the heart of a number of recent conferences. One of these, the international conference on Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A Review of Science, Policies and Practices (Umeå, Sweden, August 2008), spawned the contents of this special double issue of *Unasylva*. The conference, organized by FAO, the International Union of Forest Research Organizations (IUFRO) and the Swedish University of Agricultural Sciences, brought together over 300 researchers, managers and decision-makers from 50 countries.

This issue includes a varied sample of presentations from the Umeå conference. Interested readers will find other generally more technical offerings, as well as further detail on some of the studies covered here, in upcoming issues of *Forest Ecology and Management* and *Forest Policy and Economics.* Both were planned, in coordination with *Unasylva*, in lieu of published proceedings.

Key issues. The first article, by P. Bernier and D. Schoene, sums up observations from the Umeå conference. After an overview of impacts of climate change (which we take to include climate variability throughout this issue) on forest ecosystems, their goods and services, and people and livelihoods, it appraises measures for planned adaptation of forest management practices. It reviews the role of science in supporting planned adaptation, and the need to modify policies and institutions. The authors stress the need for countries and sectors to tackle this global issue in a collaborative way, and the need to narrow the gap between developed and developing countries in terms of scientific, planning and operational capacity for adaptation.

The second article, developed by B. Osman-Elasha from her keynote presentation, examines the predicted impacts of climate change in Africa and the links between climate change and sustainable development. While the article does not focus on the forest sector *per se*, these links should be considered by anybody concerned with how the forest sector in developing countries will adapt to climate change. Key terms are defined: vulnerability, adaptation, adaptive capacity. The central message is that since climate change is a constraint to development, and sustainable development is a key to capacities for mitigation and adaptation, sustainable development and climate change should be addressed together.

A 13-million hectare outbreak of mountain pine beetle in the province of British Columbia, Canada exemplifies the devastating effects that a warming climate can have for the landscape, forest industry and forest-dependent communities. D. Konkin and K. Hopkins, recapping another Umeå keynote presentation, summarize the challenges faced and lessons learned. The epidemic has increased recognition of the need to develop resilience in ecosystems, people and communities, and has forcibly broadened the thinking and approach of British Columbia's forest managers. In addition to investment in reforestation of affected areas, the government's responses emphasize recovering the economic value of killed trees through rapid harvest for timber, promoting the use of wood in construction, and economic diversification in forest-dependent communities.

Impacts on forest species composition and distribution. The next few articles highlight some efforts to predict effects of climate change on forest ecosystems and the distribution of forest species. M. van Zonneveld and co-authors used climate envelope modelling to predict possible shifts in the distribution of two tropical pine species, *Pinus kesiya* and *Pinus merkusii*, in Southeast Asia; the aim was not only to anticipate impacts, but also to identify opportunities, such as the potential for pine plantations in areas where they were not previously possible.

M. Silveira Wrege *et al.* used climate vulnerability mapping to predict areas in Brazil where climate change might have the greatest effects on *Araucaria angustifolia*, so that these areas can be prioritized for conservation activities.

A short contribution by M. Devall summarizes how global climate change might make rare trees and shrubs – those most in need of conservation efforts – more vulnerable because of their small populations, habitat specialization or limited geographic range. D.I. Nazimova *et al.* analyse 350 years of post-fire succession in the subtaiga forests of southern Siberia, Russian Federation to predict how increased fires (a likely result of climate change) could influence their future composition, since fire is the main factor determining biodiversity, regeneration and dominant tree species in these forests. Adaptive management plans in this zone will thus need to emphasize fire protection.

Impacts on forest health. Changing climate will also influence forests through impacts on other biotic factors such as pests and diseases. Climate change in some areas is already providing insect species with increasingly hospitable habitats, while their movement is further facilitated by wider global commerce. J. Régnière (an Umeå keynote speaker) describes an approach for predicting distributions of insect pest species under climate change, based on their physiological responses to specific weather factors. He notes that the distribution of most insect species can be expected to shift towards the poles and to higher elevations, with greatest impact in temperate regions – but that shifts in distribution do not necessarily mean that the world will have more pests.

C.D. Allen finds that beyond impacts of expanding human populations and economies, ongoing climatic changes are influencing the condition of forests all over the world. He traces patterns of dieback (tree mortality well above the norm) primarily related to drought and warmer temperatures. Although gaps in knowledge currently limit the conclusions that can be drawn about trends in forest mortality, Allen suggests that many forests and woodlands today may be at increasing risk of climate-induced dieback. An illustrated map supports the case with examples from all forested continents.

What science and policy can do. Can tree improvement programmes offset new forest health problems that may be expected to arise with climate change? Based on a survey of existing programmes to develop pest and disease resistance in trees, A. Yanchuk and G. Allard observe that most progress has been made for only a small number of major commercial species and has taken decades to achieve. The article suggests that in a world with rapidly changing climates, where new insect pest and disease introductions and increased damage from native pests are likely, past approaches may not be fast enough. The authors recommend that research focus on the search for more general forms of resistance against various classes of insects or diseases that could be developed in advance of outbreaks.

G.M. Blate *et al.* offer practical options for adapting forest management goals and practices to expected climate change impacts, as identified for national forests in the United States. They outline short-term adaptations for building resistance and resilience, and longer-term adaptations for managing for change as resilience thresholds are crossed. They stress the need to strengthen the relationship between scientific research and forest management; to assess trade-offs and synergies between mitigation and adaptation options; to use participatory decision-making to embrace all stakeholders' concerns; and to focus on realistic outcomes, confronting what can and cannot be done given limited financial and human resources.

S. Mansourian, A. Belokurov and P.J. Stephenson examine the role of forest protected areas in adapting to climate change, drawing on examples from the global work of the World Wide Fund for Nature (WWF). They summarize a range of management and policy responses for ensuring that forest protected areas continue to support biodiversity conservation in the face of climate change – for example, designing, planning and managing protected areas in landscapes to improve their resilience and species' freedom of movement. The authors stress that in a future in which climate change will add to the pressure on natural resources caused by growing populations, protected areas will be viable only if they are directly relevant to human communities that live in or depend on them

Community adaptation. What can communities do to adapt? B.A. Gyampoh and co-authors surveyed 20 rural communities in Ghana to examine the use of traditional knowledge to cope with impacts of climate change, particularly water shortage. Indigenous people live close to nature and are often the first to note and adapt to its changes. Strategies for adaptation and coping could benefit from combining scientific and indigenous knowledge, especially in developing countries where technology is least developed. The authors call for further study towards integrating indigenous adaptation measures in global adaptation strategies and scientific research.

M. Idinoba *et al.* briefly examine the impacts of climate change for communities that depend on non-wood forest products in West Africa. They cite research in Burkina Faso that has shown reduction in the distribution, availability and productivity of some NWFP species due in part to climate change. The authors describe forest management and conservation practices adopted to reduce vulnerabilities.

The issue finishes with a comprehensive review of ecosystem sensitivities to climate change, its likely future impacts on goods and services and possible adaptation options in a particularly vulnerable ecosystem: mountain forests. Focusing on temperate and Mediterranean mountain forests in Europe, M. Maroschek and co-authors note the importance of choosing suitable species and reproductive material; adapting spacing, tending and thinning schemes for expected future conditions; adopting preventive (e.g. pest monitoring) and remedial (e.g. sanitation felling, pest control) forest protection routines against the possibility of increased disturbances; and supporting adaptive management options by reducing other pressures through integrated environmental management.

In this special issue, even the usual sections on FAO Forestry, World of Forestry and Books highlight the theme of forests and climate change.

Climate change presents a moving target – so it will be necessary to assess risk and reduce vulnerabilities to predicted changes. We hope that the knowledge presented here can help the forest sector prepare for changes to come.

Adapting forests and their management to climate change: an overview

P. Bernier and D. Schoene

A synthesis of observations from the international conference on Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health, held in Umeå, Sweden in August 2008.

Pierre Bernier is a Research Scientist at the Laurentian Forestry Centre, Canadian Forest Service, Natural Resources Canada, Quebec. Seconded to FAO, Rome as a visiting expert for six months in 2008, he helped organize the conference in Umeå, Sweden on which this issue of *Unasylva* is based.
Dieter Schoene, forest and climate change specialist, retired from the FAO Forestry Department in 2007. He was a keynote speaker at the Umeå conference.

Forest adaptation to future environmental or social conditions resulting from climate change may significantly alter how and why forestry is practised in many parts of the globe. With the climate, and as a result the environment, undergoing perceptible changes within the life span of trees, achieving sustainable forest management will increasingly resemble aiming at a moving target.

The Intergovernmental Panel on Climate Change (IPCC, 2007) has concluded that warming of the climate system is unequivocal and most likely due to the observed increase in anthropogenic greenhouse gas concentrations in the atmosphere. In addition to the rise in average global temperatures, discernable changes have been observed in day, night and seasonal temperatures, in the frequency, duration and intensities of heat waves, droughts and floods, wind and storm patterns, frost, snow and ice cover, and in global sea levels.

Anthropogenic warming has already caused many changes in forests. As large, extensively managed, long-lived ecosystems, often on marginal sites, forests respond sensitively to climatic changes, together with the people, societies and economic activities that depend on them. IPCC rated boreal, mountain (see article by Maroschek *et al.*, this issue), Mediterranean, mangrove and tropical moist forests as the forest ecosystems most likely affected by climate change.

Forests also influence climate change, as sources of greenhouse gases when they are destroyed and as sinks for carbon when they grow or expand. The Bali Action Plan adopted by the thirteenth Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2007 proposes that forests in developing countries be considered a prime tool for climate change mitigation. Activities currently addressed include reducing emissions from deforestation and forest degradation in developing countries (REDD) and conservation and enhancement of carbon stocks through sustainable forest management.

Millions of indigenous forest dwellers depend directly on forests and their products. More broadly, forests contribute to human well-being through a well-known range of services. Hence, adaptation of forests to climate change is of critical importance. Locally, forest management and silviculture are likely to influence carbon sequestration by trees, the reaction of forests to climate change and the forest services provided to local populations. Here, mitigation and adaptation must meet.

Current observations and projections provide a first estimate of the adaptation measures that will be needed to cope in forestry and eventually in other sectors. Although the outlook is blurred by uncertainty, actions in today's forests link the present generation to those of the future, underscoring the need to incorporate adaptation to climate change in current forest management practices.

In August 2008, the international conference on Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A Review of Science, Policies and Practices brought together about 330 researchers, managers and decision-makers from

50 countries to discuss these issues (see www.forestadaptation2008.net). The conference was held in Umeå, Sweden and organized by the Swedish University of Agricultural Sciences, the International Union of Forest Research Organizations (IUFRO) and FAO. The following text captures some of the observations and ideas that emerged from the presentations and discussions.

CLIMATE CHANGE IMPACTS – PAST AND FUTURE

Forest ecosystems and their goods and services

At the local level, attributing a single extreme event to climate change is difficult. Climate is inherently variable and extreme events are not uncommon. An occasional insect outbreak or drought-induced mortality in one location may result from or be enhanced by natural climate variability. In many cases the absence of long-term, reliable records makes it difficult to determine if the frequency of extreme climatic events is increasing or not. At the global level, however, the current number and scale of such events provides strong circumstantial evidence of widespread and unusual changes in forest ecosystems (see article by Régnière).

Temperate and boreal forests experience reduced snow cover and earlier snowmelt, shorter frost periods and more extreme weather, which increases the likelihood, frequency, extent or severity of drought, heat waves, floods and intense storms. Forest fire seasons in many parts of the world are now longer or more severe. Warmer temperatures, coupled at times with poor forest management, have also predisposed some of the large, homogeneous forest ecosystems to outbreaks of insects, diseases and other pests. A vivid example is the current outbreak of mountain pine beetle (*Dendroctonus ponderosae*) that has ravaged more than 13 million hectares of forests in western Canada. Tropical forest ecosystems have experienced increased temperatures and more frequent and extreme El Niño–Southern Oscillation (ENSO) events resulting in a greater incidence of intense cyclones, extreme drought, fires, flooding and landslides. Lower river flow and higher storm surges are raising water salinity in mangroves and other coastal forested wetlands, leading to degradation of these vital ecosystems.

In arid and semi-arid lands, drought has increased tree mortality and resulted in degradation and reduced distribution of entire forest ecosystems, such as the Atlas cedar (*Cedrus atlantica*) forests of Algeria and Morocco. As drought reduces the productivity of adjoining agricultural land, many African communities with limited economic alternatives are likely to turn to the forests for crop cultivation, grazing and illicit harvesting of wood and other forest products, aggravating the local loss of forest cover.

The impacts of future climate change on health, growth, distribution and composition of specific forests cannot be predicted with certainty (see articles by van Zonneveld *et al.* and Silveira Wrege *et al.*). Local climate projections are still rare. In addition, biotic and abiotic factors can interact unpredictably. Growth may be stimulated by warmer seasons, longer growing seasons and the fertilizing effect of increased atmospheric CO_2 concentrations, as long as moisture or nutrient availability is not limiting. However, more frequent stand-replacing disturbances with abrupt, large and localized losses are foreseen (see article by Allen). Some climate change models predict a catastrophic dieback of parts of the Amazon and other moist tropical forests which would exacerbate global warming.

Changes to forests due to climate change may be aggravated by other human-induced changes in the natural environment. Ground-level ozone, a strong phytotoxic agent prevalent in developed countries, reduces tree growth. Nitrogenous pollutant deposition may enhance growth but may also cause nutrient imbalances. The accidental introduction of insect pests and pathogens via intercontinental trade, which has already profoundly altered many forest ecosystems worldwide, increases risks of large-scale infestations as climatic barriers to pest estab-

Warmer temperatures have predisposed coniferous forest in western Canada to a severe outbreak of mountain pine beetle (*Dendroctonus ponderosae*) extending over more than 13 million hectares

BRITISH COLUMBIA MINISTRY OF FORESTS AND RANGE/L. MACLAUGHLAN

In arid and semi-arid lands, drought has increased tree mortality and resulted in degradation and reduced distribution of entire forest ecosystems, such as the Atlas cedar (*Cedrus atlantica*) in Morocco

FAO/FO-6178/G. ALLARD

lishment or proliferation are gradually lowered in high-latitude forests. Better management of these factors will help in the adaptation of forests to climate change.

The emerging pattern of current and future climate change impacts on forests is one of abrupt negative impacts from a wide spectrum of climate-related causes, and of more subtle negative and positive impacts that arise in some regions or at particular sites, often only for certain tree species. Overall, the risk for forests and for forest management over typically long rotation periods will increase steeply in most areas of the globe, and productivity gains of some forests are likely to be eradicated by disturbance. The environment for forestry is likely to become much more difficult during the course of this century.

People and livelihoods

Richer societies in industrialized countries have the means for dealing with the more immediate effects of climate change and are less prone to suffer in the short term. In contrast, the economic and human welfare impact of climate change can be severe for the many poor communities in developing and least-developed countries that depend on forests for food, fodder, fuelwood, medicines and ecosystem services. Water shortages and unpredictable rainfall, in combination with continued population growth and land degradation, increase pressure on forest ecosystems and their capacity to meet immediate livelihood needs. The promotion of community forestry in many developing countries may increase local adaptive capacity by putting decisions in the hands of the people who feel the effects of climate change first, and by enhancing the role of traditional knowledge in forest management (see article by Gyampoh *et al*.).

Even in developed countries, some communities depending on forest-based industries or located in forested landscapes are already affected by climate-related forest disturbance. In Canada, for example, the increased incidence of forest fires in boreal forests endangers population health and safety, and the vast mountain pine beetle outbreak will inevitably result in a major restructuring of the forest-based industrial sector, with consequences for the welfare of local populations (see article by Konkin and Hopkins).

Climate change also affects local revenues from tourism and recreational services when vast areas of dead or dying forests reduce scenic appeal or when sparse snow cover shortens skiing seasons.

ADAPTING FOREST MANAGEMENT PRACTICES

There are three possible approaches for adapting forests to climate change: no intervention, reactive adaptation and planned adaptation. Unfortunately, most current management belongs to the first or at best the second category.

No intervention means business as usual, with management targets and practices based on the premise that the forest will adapt more or less as it has in the past. Reactive adaptation is action taken after the fact, "crossing the bridge when we come to it"; examples include salvage cutting, post-disturbance changes in industrial processes to convert salvaged timber, updated harvest scheduling, recalculated allowable cuts and development of socio-economic support programmes for affected localities.

Planned adaptation, on the other hand, involves redefining forestry goals and practices in advance in view of climate change-related risks and uncertainties. It involves deliberate, anticipatory interventions at different levels and across sectors. At the community level, planned adaptation may include diversification of forest-based and non-forest based income sources, better local governance of forest resources and capacity building for monitoring and coping with possible calamities of unprecedented extent. Within the industrial forest sector, planned adaptation may involve the inclusion of bioenergy as a product or the promotion of wood products for their low carbon footprint. At the national and global levels, planned adaptation may include a timely monitoring and reporting system and the development of tools for vulnerability assessments and adaptation planning. Forest managers might also be increasingly required to weigh global implications of local interventions, as forests are part of global biogeophysical and biogeochemical cycles and are increasingly subject to international agreements or to certification schemes.

It may be argued that good forest management always involves planned adaptation. However, planning for climate change involves much greater uncertainty, novel risks and systematic risk reduction in response to anticipated events. Planned adaptation also includes exploring new opportunities that arise as a result of climate change, for example planting provenances or species that will grow faster under projected climatic conditions, or reaping the benefits of new products and services such as carbon sequestration and new forms of bioenergy. Planned adaptation may reduce vulnerability and increase resilience, or it may entail diversification at the expense of productivity.

At the stand level, planned adaptation may mean planting a larger diversity of species or provenances, or trees bred for resistance to expected stressors. Modification of thinning schedules may help stabilize stands against drought, storms and disease and may also help capture added growth from CO_2 fertilization.

At the scale of landscapes, planned adaptation may include measures to minimize the potential impacts of fire, insects and diseases, increased afforestation and reforestation, creation of biodiversity corridors (see article by Mansourian, Belokurov and Stephenson) and rehabilitation of degraded forests. At the scale of a forest management unit, adaptation options may include vulnerability assessments and increased preparedness for disaster. Finally, forest management planning can no longer be based solely on growth and yield trajectories over time. Management plans must incorporate uncertainty and the increased probability of extreme events, as well as the periodic comparison of projections against the evolving reality so as to update targets and methods.

Intensive forest monitoring is a key component of planned adaptation and will probably require additional technical and human resources. Monitoring can provide early warning of forest dieback and of pest and disease outbreaks, help reduce uncertainty in planning, and minimize losses. After an extreme event, rapid damage assessments are useful for planning timber salvage and conservation and predicting impacts on timber supplies, markets and socio-economic conditions. Most developed countries with significant forest cover already track tree growth and forest status; these efforts have sometimes been broadened to include aspects related to climate change such as monitoring of carbon and forest health. In developing countries, lack of funding and expertise for monitoring and assessment may hinder early detection of climate change impacts and timely responses. Here planned adaptation must start with capacity building for periodic forest assessments.

Combining forest monitoring and current knowledge of possible climate change impacts into vulnerability or risk assessments is the first vital step in developing an adaptation strategy. Such assessments can be used to identify where risk management is worthwhile and where the repertoire of response options in the forest sector is currently insufficient. Developing, testing and improving risk assessment methods can also provide new focus for monitoring.

SCIENCE TO SUPPORT PLANNED ADAPTATION

Climate change has permeated into many fields of environmental research, including forest ecology and forest management. Researchers increasingly need to interact with policy-makers and managers to ensure the relevance and effective application of research. In this respect, IPCC has been crucial and successful, transmitting authoritative technical information to policy-makers in readily accessible form. It has also heightened the awareness of the research community to the type of information needed by decision-makers and has reached out effectively to the public. Science–policy dialogue has flourished in national administrations as countries around the world have had to take a stance on climate change related issues in national policies and international negotiations.

Monitoring of forests is vital to planned adaptation to forest management. Multi-scale monitoring can detect changes in forest status and health early. Remote sensing may facilitate early detection and mapping of forest health calamities and may prove particularly useful in areas lacking systematic ground surveys or as a stratification tool for subsequent ground surveys; improved frequency of coverage and resolution make it possible to capture even ephemeral, small-scale phenomena.

Risk assessments of changes in forests, and of changes outside the forest sector that could have impact on forests, are another key to effective adaptation; they will need to be designed to incorporate the complexities of forest responses to stress.

Although the most striking forest changes attributed to climate change are occurring at high latitudes, smaller changes in tropical climates may have large effects on vegetation because of the complex interdependence of forest organisms and their narrow climatic niches. Vulnerability and risk assessments for the tropics are thus particularly challenging.

The development of planting stock with desirable genetic traits may be a promising avenue to counter changes in the local climate. Achieved gains in

Agroforestry has potential for providing benefits from adaptation–mitigation synergies in developing countries because it enhances diversification, reduces risk and helps stabilize livelihoods (windbreak using Alnus acuminata*, Ecuador)*

FAO/CFU000907/R. FAIDUTTI

productivity and drought resistance suggest further potential for improvement of many commercially important species, although the need for stock that can thrive under current as well as future conditions presents a particular challenge.

Prospects for developing resistance to new pests or diseases through traditional breeding programmes, however, appear limited. After some 50 years of tree breeding, few gains have been made in this regard, except for major diseases in a few commercially important species, e.g. leaf rust in poplars (see article by Yanchuk and Allard). Emerging forest health risks in tropical plantations of exotic species also suggest a need for improved approaches in forest genetics.

Climate change accentuates uncertainty, but dealing efficiently with uncertainty and risk is not a well-developed concept in traditional forestry sciences. Climate scientists and IPCC have learned to communicate climate uncertainties quantitatively. Now forest managers and policy-makers must learn to integrate these probabilities systematically into planning and decisions on the ground. Expertise in managing uncertainty and risk might also be brought in from fields in which it is common, such as management science, operations research, financial management, insurance and engineering.

Finally, impetus for change in the forest sector and in society comes chiefly from socio-economic, not ecological, crises. It is therefore only by linking the physical events to their socio-economic impacts that scientists can fully inform policy-makers. This will involve elevating the importance of the social and behavioural sciences in forest management.

ADAPTING POLICIES AND INSTITUTIONS

Lessons may be learned from current forest crises linked to climate. The mountain pine beetle outbreak in Canada, for example, has underlined some key messages (see article by Konkin and Hopkins). Catastrophic events happen abruptly and overtax conventional knowledge and normal forest management structures. Data are important, but are often insufficient to change people's attitudes. Appropriate responses often require a dramatic departure from conventional views and practices. The challenge of planned adaptation, therefore, is to make organizational culture, established structures and forest management policies more flexible before crises arise.

Adaptation to climate change and mitigation of climate change are often considered separately but may be linked to provide greater benefits (see article by Blate *et al.*). In all countries, mitigation actions such as afforestation or curbing of deforestation need to be properly planned and linked to local adaptation policies in related sectors to help local people better their livelihoods and withstand negative effects of climate change.

It is particularly urgent to channel benefits from adaptation–mitigation synergies to local populations in developing countries (see article by Osman-Elasha). Agroforestry holds great potential in this regard because it enhances diversification, reduces risk and helps stabilize livelihoods. Agroforestry practices sequester only modest amounts of carbon per hectare, but trees, bamboos and palms can be combined in almost unlimited ways with agricultural crops, garden products, grazing or fishponds on a huge area worldwide.

Adaptation and mitigation can also meet within the concept of REDD. Conceived as a mitigation option to reduce global emissions of CO_2 to the atmosphere, REDD can best succeed by encouraging sustainable forest management in developing countries. Sustainably managed forests can better adapt to climate change, and sustainable management can reduce or reverse forest loss and degradation and enhance forest resilience to climate change. For developing countries, REDD also represents adaptation in the sense of exploiting novel opportunities created by climate change in the form

FAO/FO-6141/R. VERMA

Climate change mitigation efforts need to support local adaptation of people and communities (India)

of incentive payments, carbon sales and investments in forests.

One of the problems regarding the linkage between adaptation and mitigation is that adaptation is often a response to local circumstances and is therefore a local concern benefiting local populations, while mitigation is a response to a global concern and is usually dealt with at the country scale. The challenge of mitigation policies such as REDD, particularly in developing countries, is therefore to ensure that significant benefits from mitigation actions flow to communities or forest owners. The best manner of doing this may be to ensure that mitigation actions promote local adaptation to climate change and that they fit within an overall effort of decreasing the vulnerability and poverty of local communities.

Adaptation is also essential for industries, as climate change is a new variable in their operating environment. The production and use of products from sustainably managed forests also contributes to mitigation, as wood is one of the few truly renewable raw materials available, and products made from it store carbon. In many countries investment in wood production through improved silviculture or planted forests represents a joint mitigation and adaptation measure. Wood-based products are low-emission alternatives to steel and concrete, can be recycled and could be used for bioenergy at the end of their life cycle, enhancing their appeal as environmentally sound products. Where a net energy saving can be demonstrated, policies for diverting discarded solid wood materials from the traditional waste stream towards bioenergy facilities would have the double advantage of reducing methane emissions from landfills (in landfills not equipped to capture such emissions) and substituting fossil fuels. Development of the bioenergy market can also be used as an adaptation measure in areas that have suffered mass forest mortality. Coherent energy polices concerning the entire forest products value chain, in combination with awareness raising and incentives to encourage appropriate consumer response, could play an increasingly important part in mitigating climate change.

CONCLUSIONS

The health of many forest ecosystems is already affected by climate change, and the impact is likely to accelerate, with local and global negative consequences that will likely outweigh growth increases linked to climate change. Adaptation is possible, but it is essential to plan and act soon to avert the most detrimental impacts and capture the opportunities. Awareness of actual and potential impacts from climate change, assessment of uncertainties and inclusion of risks should form the backbone of adaptation policies in forest management planning. The main challenge may be to promote planned adaptation in the absence of immediate crisis, especially when planned adaptation means reducing the potential long-term gains that would be realized in the absence of climate change. Reactive adaptation may be the most natural option but will hurt forests and society in the long term.

Reducing deforestation in developing countries (REDD) is now high on the global climate change agenda, but it is not clear how internationally negotiated modalities and eventual national implementation will affect the people whose livelihoods depend totally or partially on forests. This potentially powerful option for climate change mitigation and adaptation can only succeed through sustainable forest management and ensuring that mitigation efforts support local adaptation of people and communities.

A message that stands out clearly from the Umeå conference is the large gap between developed and developing countries in terms of scientific, planning and operational capacity for adaptation. While many developed countries invest in large multidisciplinary efforts aimed at refining risk assessments and at implementing adaptation and mitigation, many developing countries face enormous deficits in information, leadership and funding essential to implementing adaptation, and are also constrained to focus on more immediate needs. Poverty and instability make planned adaptation difficult, and in vulnerable environments large negative impacts of climate change on livelihoods may be unavoidable. In these countries, all policies related to forest-based mitigation and adaptation of forest management to climate change need to be linked with rural development and agricultural policies that focus on people, poverty alleviation, food security and livelihoods. Planned adaptation is for the common good. Equity issues and technical capacity building are necessary components of the forest sector's adaptation to climate change in developing countries and thus call for attention from the global community.

Climate change highlights more clearly than ever the need to tackle global issues in a multisectoral manner and necessitates collaboration among countries. Regional and national institutions responsible for forest stewardship and management are stepping up collaboration on this issue. Specialized institutions and governance mechanisms are slowly taking shape as the scale of the challenge and the consequences of not tackling it globally become clear. ◆

Bibliography

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate change 2007: synthesis report*. IPCC Fourth Assessment Report. Geneva, Switzerland.◆

Climate change impacts, adaptation and links to sustainable development in Africa

B. Osman-Elasha

Strategies for sustainable development and climate change adaptation have many common elements, so addressing them jointly can create synergies.

Sustainable development, defined as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (WCED, 1987), entails a harmonious integration of a sound and viable economy, responsible governance, people's empowerment, social cohesion and ecological integrity. Sustainable development does not mean economic stagnation or giving up economic growth for the sake of the environment; it should entail promoting economic development as a requisite for maintaining environmental quality. Economic development leads to increased capacity to address environmental and social problems. Maintaining environmental quality, in turn, is essential for sustainable development.

The link between climate change and sustainable development stems from the fact that climate change is a constraint to development, and sustainable development is a key to capacities for mitigation and adaptation (see Box). It follows that strategies for dealing with sustainable development and climate change have many common elements so that applying them together creates synergies. It also follows that since dealing with climate change exclusively could be very expensive, it has to be factored into the development agenda.

CLIMATE CHANGE IN AFRICA

Observed and projected climatic changes

The Intergovernmental Panel on Climate Change (IPCC, 2007a) has reported a warming of approximately 0.7°C over most of the African region during

Some definitions from the Intergovernmental Panel on Climate Change

VULNERABILITY TO CLIMATE CHANGE

The degree to which a system is susceptible to, or 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.

ADAPTATION TO CLIMATE CHANGE

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

ADAPTIVE CAPACITY

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.

Source: IPCC, 2007b.

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FAO/CFU000352/R. FAIDUTTI

Habitats and ecosystems in Africa are under threat from a variety of stresses such as deforestation, land degradation and heavy dependence on biomass for energy, to which climate change is likely to be an additional stress factor

the twentieth century. This warming occurred at the rate of about 0.05°C per decade, with slightly more warming in the season from June to November than from December to May. A temperature rise of about 0.1°C per decade is expected for the next two decades, even if greenhouse gas and aerosol concentrations are kept at year 2000 levels.

IPCC has reported that extreme events, including floods and droughts, are becoming increasingly frequent and severe. Certain regions of Africa are more prone to such extreme events than others. It is probable that the increased frequency of recorded disasters is a result of a combination of climatic change and socio-economic and demographic changes.

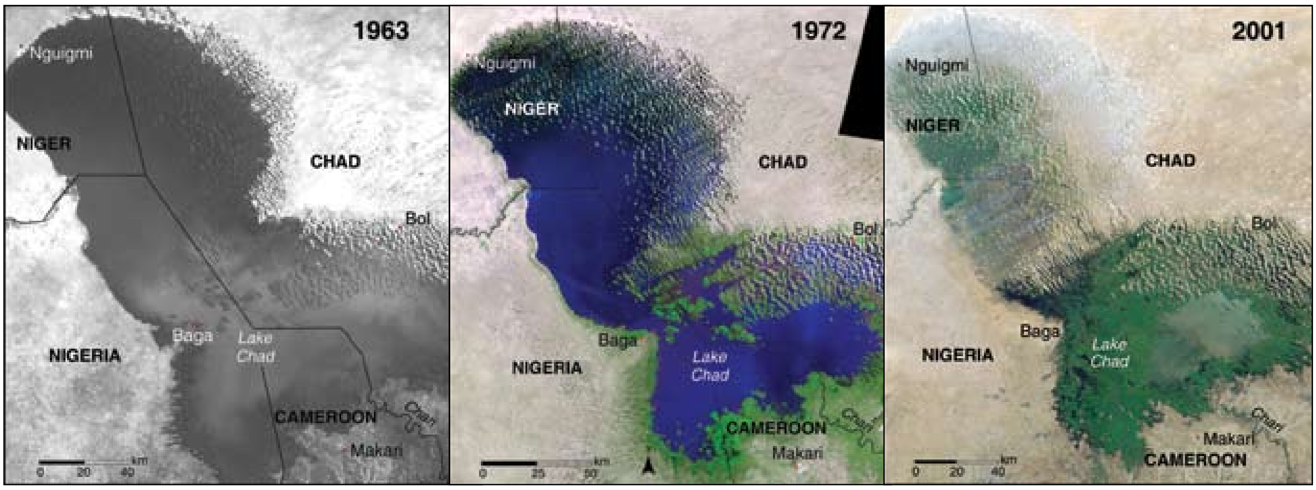
What climate change means for Africa

Habitats and ecosystems in Africa are currently under threat from a variety of stresses such as deforestation, land degradation and heavy dependence on biomass for energy. In sub-Saharan Africa over 80 percent of the population depends on traditional biomass for cooking (United Nations, 2007). Climate change is likely to be an additional stress factor (Figures 1 and 2).

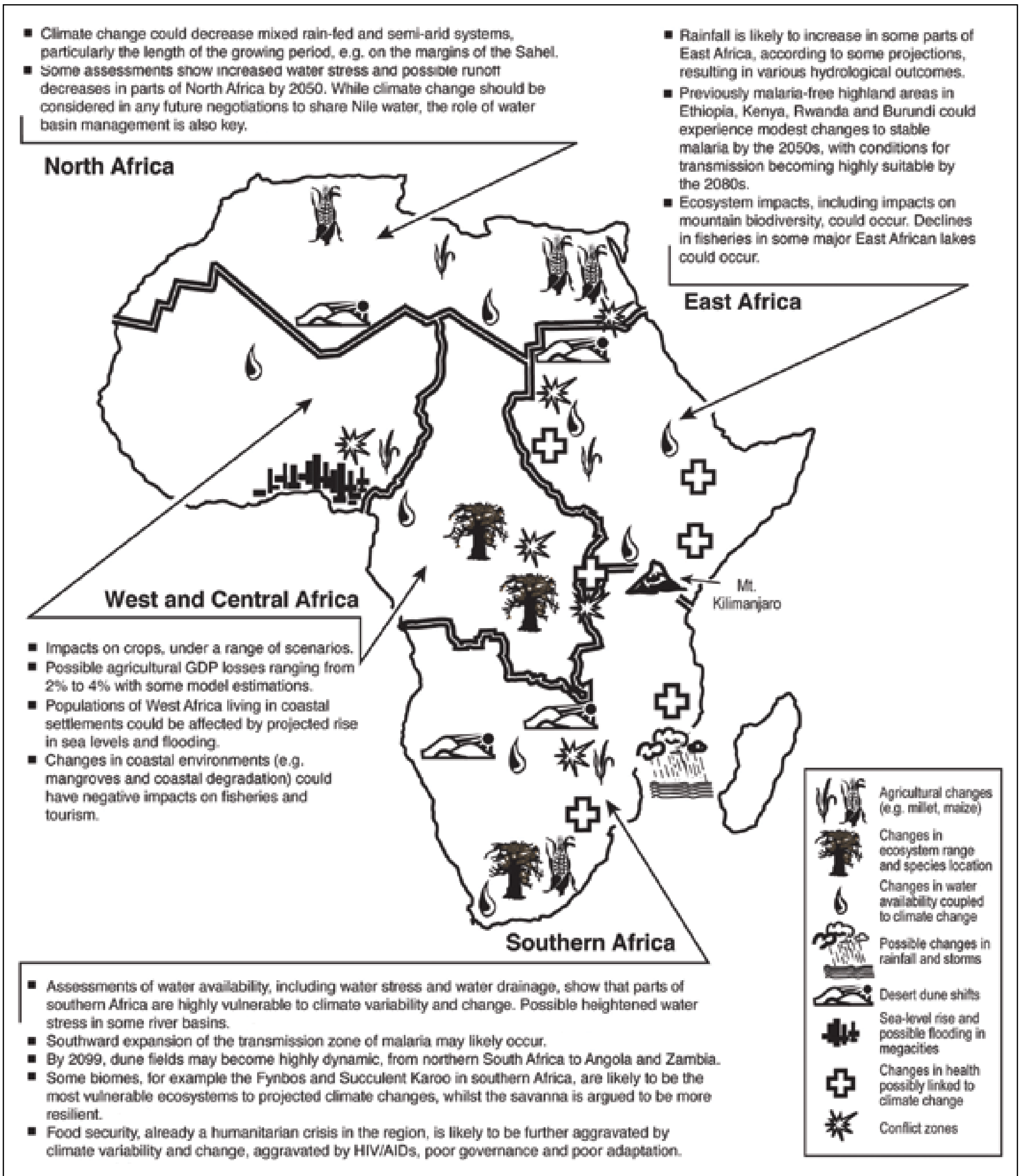
The key vulnerable sectors identified by IPCC (2007b) include agriculture, food and water. Sub-Saharan Africa is expected to suffer the most not only in terms of reduced agricultural productivity and increased water insecurity, but also in increased exposure to coastal flooding and extreme climatic events, and increased risks to human health.

Africa's vulnerability to climate change is exacerbated by a number of non-climatic factors, including endemic poverty, hunger, high prevalence of disease, chronic conflicts, low levels of development and low adaptive capacity. The average income per capita in most African countries is lower now than it was 30 years ago. Sub-Saharan Africa is the only region that has had negative annual growth of per capita gross domestic product (GDP), –1 percent between 1975 and 1999, compared with 6 percent for East Asia and the Pacific and 2.3

1
Climate change impacts on Lake Chad, showing a continued decline in lake surface area from 22 902 km² in 1963 to only 304 km² in 2001



Source: UNEP, 2008.



Source: IPCC, 2007b (Figure 9-5).

2
Climate change impacts on Africa

percent for South Asia. One-third of the people in sub-Saharan Africa suffer from chronic hunger (FAO, 2007). Four in ten people are infected with HIV/AIDS in some African countries (UNDP, 2007). The costs associated with health spending and losses in labour and productivity are greatest in some of the poorest countries; these losses amount to about 5 percent of GDP, or some US$28.4 billion annually, in sub-Saharan Africa (UNDP, 2006). Of the 25 countries in Africa that faced food emergencies in 2003, ten are currently experiencing civil strife and four are emerging from conflicts. Conflicts often divert scarce resources into military budgets and away from development needs, and result in high numbers of internally displaced persons and refugees.

Other non-climatic factors adding to Africa's vulnerability include heavy dependence on primary products; fast-growing population, leading to pressure on already degraded landscapes; poor governance and weak institutions; low capital investment; lack of access to foreign markets; poor infrastructure; inadequate technology transfer; and continuing high levels of external debt despite debt forgiveness programmes of recent years.

CLIMATE CHANGE: AN EQUITY ISSUE

Africa has the world's lowest CO_2 emissions (Figure 3). Climate change is now recognized as an equity issue because the world's poorest people, those who contributed least to the atmospheric buildup of greenhouse gases, are the least equipped to deal with the negative impacts of climate change. Wealthier nations that have historically contributed the most to global warming are better able to adapt to the impacts. Addressing disparities between developed and developing countries is integral to the success of global climate change mitigation and adaptation.

Sustainable development in Africa cannot be addressed effectively without accounting for the impacts of climate change on agriculture, conflicts and disease patterns, all of which have particular impact on the poor. Sustainable development and adaptation are mutually reinforcing; an important conclusion of IPCC is that adaptation measures, if taken up in the sustainable development framework, can diminish negative impacts from future climate change.

KEY CHALLENGES FOR AFRICA

In facing the challenges of climate change, the priorities for African countries are:

- achieving high political recognition for Africa on the platform of international negotiations;
- allocating resources appropriately;
- ensuring food and energy security;
- managing and adapting to long-term climate risk.

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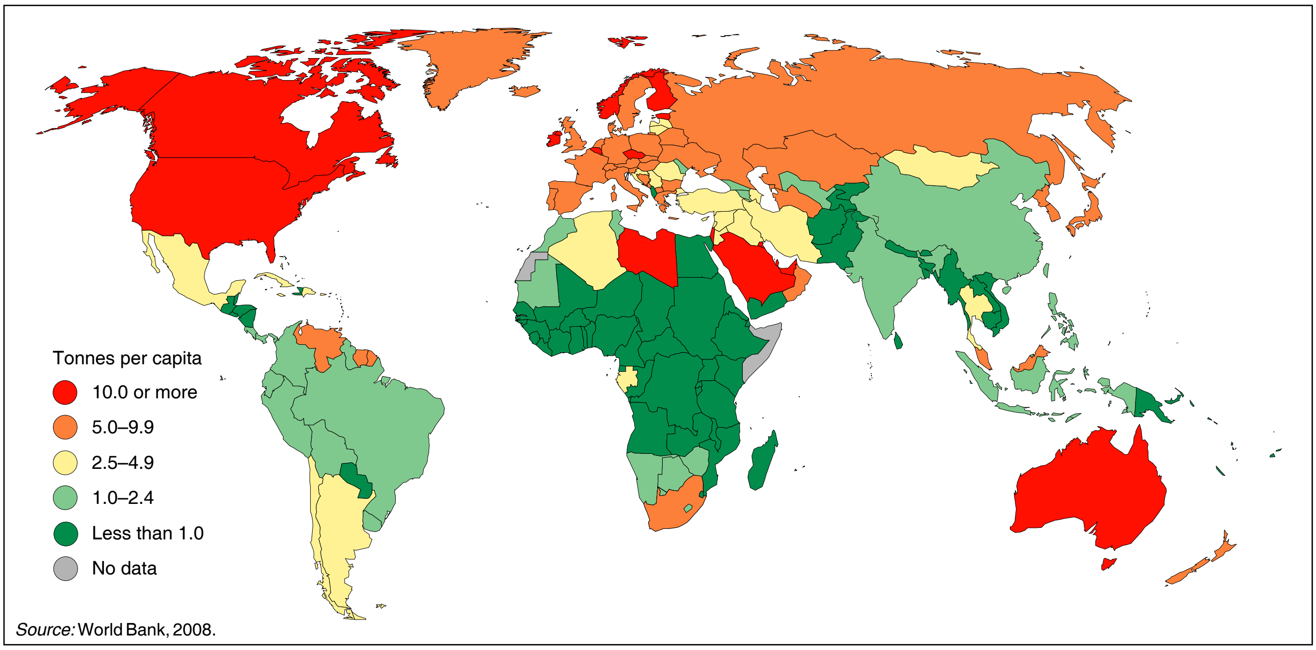
Sub-Saharan Africa is expected to suffer the most from climate change in terms of reduced agricultural productivity and increased water insecurity

3
Carbon dioxide emissions per capita, 2000



Source: World Bank, 2008.

These goals require good governance; access to technology; investment in innovation; the involvement and commitment of all segments of society; and international, national and regional cooperation.

Climate-proof development implies extra costs over and above business as usual and a need to assess and address climate risks in national development programmes. This means that additional resources are required. Who will provide them, under what mechanisms and in what time frame are the key questions to be answered. ◆

Bibliography

FAO. 2007. *State of Food and Agriculture 2007*. Rome.

Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate change 2007: the physical science basis*. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge, UK, Cambridge University Press.

IPCC. 2007b. *Climate change 2007: impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge, UK, Cambridge University Press.

United Nations. 2007. *The Millennium Development Goals Report 2007*. New York, USA.

United Nations Development Programme (UNDP). 2006. *Beyond scarcity: power, poverty and the global water crisis. Human Development Report 2006*. New York, USA.

UNDP. 2007. *Fighting climate change: human solidarity in a divided world. Human Development Report 2007/2008.* New York, USA.

United Nations Environment Programme (UNEP). 2008. *Atlas of our changing environment.* Nairobi, Kenya. Available at: na.unep.net/atlas

World Bank. 2008. *Data and statistics*. Internet document. Available at: go.worldbank.org/WVEGH5U9W0

World Commission on Environment and Development (WCED). 1987. *Our common future***.** Oxford, UK, Oxford University Press. ◆

Learning to deal with climate change and catastrophic forest disturbances

D. Konkin and K. Hopkins

A devastating outbreak of mountain pine beetle in the province of British Columbia, Canada creates challenges – but also opportunities – for policy-makers, forest industry and society.

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Kathy Hopkins is Technical Advisor – Climate Change, British Columbia Forest Service, Victoria, Canada.

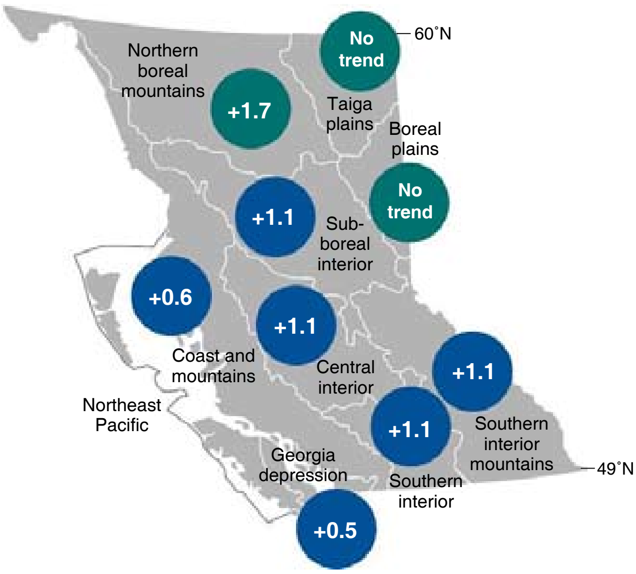
The mountain pine beetle, *Dendroctonus ponderosae*, is a native bark beetle of the lodgepole pine forests of western Canada that periodically builds to outbreak levels. However, since the late 1990s, populations have grown to an unprecedented scale, now attacking more than 13 million hectares of forest in the province of British Columbia – an area about the size of England. The epidemic may be attributed to multiple causes, including climate change and other factors such as forest management interventions. By 2015 the epidemic is expected to kill more than three-quarters of the pine volume in British Columbia. This represents over 900 million cubic metres of timber that was expected to contribute to the economic wealth of British Columbia's communities. In these communities climate change is no longer a theoretical matter – the impacts are real now.

This epidemic creates challenges on multiple fronts, but it has also led to new economic opportunities for British Columbia. It has in addition been a catalyst for increased collaboration among rural communities, natural resource industries and government agencies, and it has fostered new ways of thinking about forest management in the context of climate change and social objectives.

A raft of logs being towed to the mill illustrates the importance of forestry to the economy of the Canadian province of British Columbia

FAO/FO-6873/J. BALL

Mountain pine beetles washed up on a lakeshore give an idea of the severity of the outbreak



Note: "No trend" is reported where the weather record is too short for the analysis.

Source: British Columbia Ministry of Environment, 2002.

1
Changes in average temperature in British Columbia during the twentieth century

A FOREST PROVINCE

British Columbia, Canada's most westerly province, covers about 95 million hectares on the rugged Pacific coast. Two-thirds of its land area is forested, an area larger than France. Ninety-five percent of the province's forest land is publicly owned and managed by the British Columbia Ministry of Forests.

Forest products represented about 40 percent of the total value of all of British Columbia's exports from 1996 to 2004 (Can$15 billion [US$12 billion] per year). Forestry is the main employer in many rural communities. In 2007, the forest sector accounted for 84 000 jobs and 6.8 percent of total provincial gross domestic product. In addition to timber values, British Columbia's forests store carbon and supply water for domestic, industrial and other uses. They provide important cultural values, sustenance for First Nations peoples and a setting for tourism and recreation.

A BEETLE PARADISE

In British Columbia, lodgepole pine (*Pinus contorta*) is the single most plentiful tree species, making up 23 percent of the provincial growing stock. It grows throughout most of the province's interior from middle to subalpine elevations. It is a preferred host for mountain pine beetle. At endemic levels, this beetle breeds in weakened large-diameter trees. At epidemic levels, it attacks and kills healthy trees over large areas.

Over the past century, successful fire suppression and social constraints on harvesting led to the growth of large areas of contiguous stands of pine which have recently come to maturity, providing the mountain pine beetle with ideal habitat. The ease with which the epidemic spread through these stands has shown the value of managing age class distributions and increasing species diversity at the landscape level, as a more diverse array of species and age class distributions across the landscape would have reduced the exposure of the

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Treating mountain pine beetle with fire

province's interior forests to a single insect or pathogen.

CLIMATE EFFECTS ON MOUNTAIN PINE BEETLE DISTRIBUTION

Over the past decade, British Columbia has not experienced the extreme cold winter temperatures that curtailed previous outbreaks. Warming in British Columbia over the twentieth century (to 1995) was approximately equal to the global average of 0.6ºC on the coast (British Columbia Ministry of Environment, 2002; IPCC, 2001), but two or three times higher in the interior (Figure 1).

The higher winter temperatures led to increased winter survival of the mountain pine beetle, which has culminated in the largest beetle epidemic in the province's recorded history. By 2008, it had affected about half a billion cubic metres.

MOUNTAIN PINE BEETLE IMPACTS

The mountain pine beetle outbreak has had (or will have) many negative environmental and socio-economic impacts. Environmental impacts are not limited to the loss of mature forest cover. For example, local water table and hydrological cycles have changed. Interior forests have become a carbon source rather than a sink, and are expected to remain so until 2020. Plant and animal habitat is affected.

Although negative economic impacts will be felt over the longer term, in the short term there have been some benefits. For example, until the recent decline in the United States housing market dampened the demand for timber, economic activity in affected areas increased as the forest sector attempted to salvage as much merchantable timber as possible from beetle-killed trees before they would degrade.

There is significant variability in the length of time dead pine is useful for dimension timber, but trials have shown that in some areas beetle-damaged timber can be used up to 15 years after attack, and even later for processing into oriented strand board, wood pellets and other products (FPInnovations – Forintek, 2008; J.S. Thrower and Associates, 2007a, 2007b; Timberline Natural Resource Group, 2008). On average, the estimated shelf-life for individual pine trees ranges from 5 to 10 years, and that of pine stands from 8 to 12 years. However the dry wood degrades in quality from weather damage, splits easily and has a reduced recovery rate, so timber manufacturers have had to develop new technologies to confront this problem.

Eventually, British Columbia will exhaust the economic benefits of the large amounts of available dead wood. In some areas the mid-term timber supply will be reduced to half of the pre-outbreak harvest levels.

TAKING ACTION

Limiting the outbreak – a vain hope

In the face of a massive and expanding insect infestation, British Columbia's first action was to try to limit the spread of the outbreak. Early it became clear that the epidemic was too vast to eliminate or control, and significant funds were devoted to slowing the rate of infestation on the outer edges of the outbreak, to keep the infestation from spreading over the Rocky Mountains and into the boreal forest. Unfortunately, hopes for severely cold winter temperatures to kill insect broods have not been met, and by 2007, the beetle had spread over the Rocky Mountains on wind currents.

Recovering value

In the central area of the outbreak, efforts quickly shifted towards maximizing recovery of the economic value of dead timber before it would deteriorate. In the management units most affected, harvesting has been concentrated in stands where pine represented more than 70 percent of the available timber

CITY OF RICHMOND, BC, CANADA

British Columbia is pushing to use wood in construction – the 2.6 ha roof of the 2010 Olympic Speed Skating Oval for the 2010 Winter Olympic Games near Vancouver is constructed mainly of wood from beetle-killed trees

volume. Allowable harvest levels have been temporarily raised and policy has been changed to facilitate harvesting in these areas. Operators have moved from adjacent non-affected areas to focus on harvesting of beetle-attacked trees.

Assisting forest-dependent communities

While the increase in salvage harvesting has increased wood processing recently, over the longer term the beetle outbreak may have significant economic, social and cultural impacts on communities that have relied on logging and sawmilling for decades. British Columbia is investing in coalitions to increase community resilience by diversifying economic opportunities. These efforts are designed to provide long-term stability in a way that reflects local aspirations.

Protecting mid-term timber supply

The forest sector has also been working to mitigate the impacts on the mid-term timber supply. Approximately 30 percent of the dead pine stands have sufficient understorey to be considered fully or partially stocked. These young trees will contribute to the mid-term timber supply in many areas. Identifying and protecting understorey trees during logging operations has become an important issue.

The province has allocated new funding to reforest beetle-killed pine areas that will not be salvage harvested. In 2005 the British Columbia Government initiated a reforestation programme to ensure that the areas deforested by wildfire and mountain pine beetle grow into productive healthy forests. Support for the programme has increased to over Can$50 million (US$40 million) per year. This programme will improve the future timber supply and address risks to other forest values by re-establishing young forests on land that would otherwise remain underproductive. The reforestation programme currently plants 8 million seedlings per year and will grow to 18 million seedlings by 2010. Seventy-five million seedlings will be planted through this programme over the next five years.

Manufacturing and products

Partners in government, academia and industry are undertaking research into new manufacturing techniques, improvements in milling capacity and development of alternative products from beetle-attacked timber. So far, Can$5.9 million (US$4.7 million) has been allocated to research and development of new products and to improvement of manufacturing processes.

Because wood compares favourably with concrete and steel in both greenhouse gas emissions and energy consumption in processing, British Columbia is pushing to make wood the first choice for construction. The 2010 Olympic Speed Skating Oval for the 2010 Winter Olympic Games near Vancouver is a showcase example. One million board feet of sawnwood (2 360 m^3 [full sawn]), mostly from beetle-killed trees, were used in the 2.6 ha roof.

Because British Columbia has abundant hydroelectric power and lower reliance on fossil fuels than some jurisdictions, the province is just beginning to pursue alternative energy sources. However, the province's wood pellet industry is expanding rapidly; it produced almost 1 million tonnes of wood pellets in 2008, directly and indirectly employing about 300 people and generating more than Can$170 million (US$136 million) in revenue, primarily from exports to Europe. The abundance of cheap wood made available by the beetle infestation has also stimulated interest in cellulose-based bioenergy. British Columbia, like other jurisdictions, is moving up the value-added ladder towards gasification and other energy products, all depending heavily on market demand.

Society's values

Most of British Columbia's population lives in urban centres away from the interior forests, but the visual changes to the landscape associated with the beetle infestation and recent fires have been strong enough to create a new public awareness of forest amenity values and climate change. Bigger questions on the horizon include how climate change and forest health issues will affect traditional ways of thinking about land use, and how societal values are to be incorporated into policy decisions.

EXPECTATIONS FOR THE FUTURE

Climate projections

The average global temperature increase in the twenty-first century is expected to be between 1° and 6°C (IPCC, 2007). The actual trajectory will depend on how quickly the world curbs emissions, but the increase could easily exceed that of the past hundred years. Because of its northern location, British Columbia is preparing for further increases of this magnitude or more. These changes could have significant effects on species and ecosystems.

Understanding ecosystem responses

Climate change is one of the key drivers for the research programme of the British Columbia Forest Service. The Future Forest Ecosystem Initiative (see www.for.gov.bc.ca/hts/Future_Forests) was created in 2006 to adapt the province's forest management policies and practices to increase the resilience of forest and range ecosystems. Resilience refers to the capacity to absorb, recover from and adapt to climate change stresses.

Government scientists have been working with the University of British Columbia and other partners to develop scenarios showing how climate changes may affect forest ecosystems in the future (Figure 2). These models lead to expectations that many of the province's ecosystems will soon face climatic conditions that are more suitable for a different assemblage of species than at present. However, the species composition may not be able to change naturally as quickly as the climate does, so poorly adapted species on some sites will be under increased stress. Therefore scientists are investigating ways to assist migration of tree species and provenances into areas where the climate is likely to be suitable in the future.

Re-assessing forest policy and practices

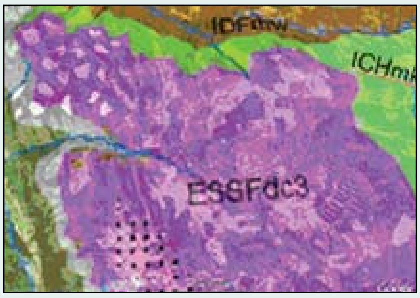
The mountain pine beetle epidemic has demonstrated the complex and often unexpected impacts resulting from a large-scale disturbance. These can occur quickly and may overtake the government's capacity to meet societal expectations.

The British Columbia Ministry of Forests and Range is starting to re-examine all its policies with a climate change lens. For example, its approach to tree breeding, which previously focused on growth, has been broadened to focus on both growth and resilience.

While climate change may bring some advantages for British Columbia's forests, in the end the costs associated with agents such as fire, pests and water are likely to far outweigh the benefits. The opportunity to adjust forest management practices is limited by the very small proportion (about 0.3 percent) of forest land that is harvested each year in the province. Therefore adaptation is necessary to make both communities and economies more resilient.

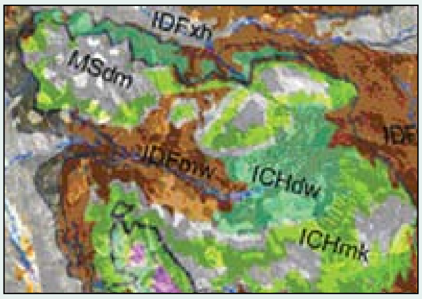
2
Climate scenarios for Cahilty Creek

Present



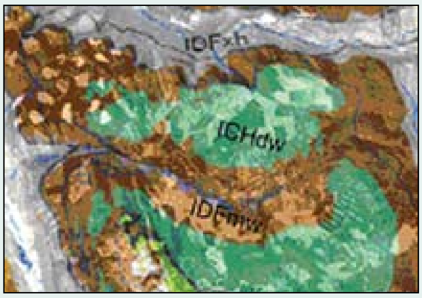
Suitable for Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) (ESSF)

2050, slow change scenario (low emissions)



Slightly warmer climate, suitable for interior western red cedar (*Thuja plicata*) and hemlock (*Tsuga *spp.) (ICH) and interior Douglas fir (*Pseudotsuga *spp.) (IDF)

2050, rapid change scenario (high emissions)



Warmer climate with drier summers, suitable for Douglas fir, ponderosa pine (*Pinus ponderosa*) and western red cedar

Source: Symmetree Consulting Group Ltd, unpublished.

Adjustment of natural and human systems to moderate the harm resulting from climate change cannot alone solve all the problems. Aggressive climate change mitigation is essential to effective adaptation. To do its part to reduce emission of the greenhouse gases that contribute to climate change, the British Columbia government has introduced a revenue-neutral carbon tax on greenhouse gas emissions produced from burning fossil fuels. The tax puts a price on each tonne of greenhouse gas emitted, creating a financial disincentive for emissions across the economy. Businesses and individuals in British Columbia can reduce their tax bill by reducing their fuel consumption, using cleaner fuels, increasing fuel efficiency or adopting new energy technology. They could even offset their emissions entirely by taking advantage of emerging carbon markets. By law, the British Columbia government must show how all of the province's carbon tax revenue flows back to individuals and businesses as tax reductions.

British Columbia is also participating with seven states in the United States and four Canadian provinces in the Western Climate Initiative, which is developing a cap and trade system to reduce greenhouse gas emissions from facilities emitting 100 000 tonnes or more of carbon dioxide equivalents per year. While deforestation in the province is small, the province is also working on provisions to reduce or eliminate net deforestation.

Social aspects

British Columbia is moving towards scenario-based planning and considering ways to build adaptive capacity in the overall forest management system. All issues are people issues, and the solution to the province's environmental challenge lies with people. Science is vital to climate change solutions but is not sufficient alone.

Currently there is public pressure to conserve old trees and to reduce or eliminate fires for air quality and other reasons. However, old trees fall prey to disturbance agents such as the mountain pine beetle, and as climate changes, public pressure to avoid burning could impair efforts to maintain healthy stands.

The British Columbia government is working to build awareness of climate change and to increase individual and organizational innovation in solving related problems. In order to succeed in addressing climate change, behavioural change is key, but most people do not change their behaviour because of data or information. It is important to recognize that climate change impacts are products of underlying patterns of human behaviour. To change those patterns and behaviours it is imperative not only to make strategic adjustments to business systems and incentives, but also to tell a compelling story and appeal to human emotions as well as reason.

IN SUMMARY

The mountain pine beetle epidemic has broadened the thinking and approach of British Columbia's forest managers. It has highlighted the potential for unintended consequences of human intervention in natural systems, and increased recognition of the need to develop resilience in ecosystems, people and communities.

To tackle the systemic challenges presented by climate change, the provincial government is developing robust systems for organizational learning, with a supportive learning environment, progressive leadership practices and active links between science and policy. It has found tremendous advantages in working across disciplines – for example forest health, timber supply analysis and community planning – to tackle climate change in a holistic way.

The problems and solutions are part of a complex system with global influences. For example, the economic growth in China affects the price of oil around the world. United States corn subsidies affect the global area of land used for fibre and food production. Russian log tariffs affect log prices in international trade. A mountain pine beetle infestation in British Columbia influences United States timber prices. All of these affect British Columbia's ability to sustain an even supply of wood to support forest-dependent communities.

The questions outnumber the answers. British Columbia's approach is to develop and test a range of future scenarios, not just for the climate but for ecological and human systems. This means changing how different levels of government and government agencies interact with each other, with industry and with communities. Innovations are appearing in areas of overlapping interests; for instance energy companies are partnering with forest companies, creating opportunities for new technology and new products.

No single community or agency can be prepared for the changes that will be seen in the future. Leaders need to support diversity; avoid creating rigid organizational hierarchies that deter innovation, and be inclusive, open and questioning. ◆

"10 billion beetles can't be wrong – buy BC pine"

Bibliography

British Columbia Ministry of Environment. 2002. *Indicators of climate change for British Columbia 2002*. Victoria, British Columbia, Canada. Available at: www.env.gov.bc.ca/air/climate/indicat

FPInnovations – Forintek. 2008. *Predicting yields from post MPB attacked sawlogs*. Canadian Forest Service Internal Report for Project 5754.

Intergovernmental Panel on Climate Change (IPCC). 2001. Summary for policymakers. In *Climate change 2001: the* *scientific basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK & New York, USA, Cambridge University Press.

IPCC. 2007. Summary for policymakers. *In* S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M.B. Tignor, H.L. Miller Jr. & Z. Chen, eds. *Climate change 2007: the physical science basis*, pp. 1–18. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK & New York, USA, Cambridge University Press.

J.S. Thrower and Associates. 2007a. *Shelf life study on log quality and volumes in mountain pine beetle-killed lodgepole pine in the B.C. central interior*. British Columbia Ministry of Forests and Range Internal Report for Projects MFZ-010 and MFF-006.

J.S. Thrower and Associates. 2007b. *Field sampling for attributes related to the shelf life of mountain pine beetle-killed lodgepole pine in the sub-boreal spruce (SBS) biogeoclimatic zone*. Canadian Forest Service Internal Report for Project 8.38.

Timberline Natural Resource Group. 2008. *Preliminary analysis of mountain pine beetle shelf-life 2007 grey attack*. British Columbia Ministry of Forests and Range Internal Report for Project BC0108551. ◆

Impact of climate change on the distribution of tropical pines in Southeast Asia

M. van Zonneveld, J. Koskela, B. Vinceti and A. Jarvis

Climate envelope modelling is used to predict possible shifts in the distribution of Pinus kesiya *and* P. merkusii*, which could have implications for the conservation and use of their genetic resources.*

The natural pine forests of Southeast Asia consist of two widespread economically important species, *Pinus kesiya* and *P. merkusii*, and two rare endemic species, *P. dalatensis* and *P. krempfii*. During the past decades deforestation has decreased their area (FAO, 2007), despite several conservation projects (e.g. Danida Forest Seed Centre, 2000; Razal *et al.*, 2005). Unsustainable resin-tapping and fuelwood collection is degrading many of the remaining pine stands. Climate change is likely to create additional threats and affect the regeneration, growth and distribution of these pine forests.

With deforestation, the genetic resources of the pine species have been eroded. However, the remaining pine forests still include genetic resources that could be useful for rehabilitation of the degraded natural pine forests, tree improvement and establishment of tree plantations.

This article describes the use of climate envelope modelling (CEM) to estimate the potential occurrence of *P. kesiya* and *P. merkusii* in Southeast Asia under the present climate and to analyse how it may shift as a result of climate change. It also discusses the implications of the results for conservation and use of the genetic resources of these two pine species in Southeast Asia.

PINES IN SOUTHEAST ASIA

Pinus kesiya grows in the highlands (800 to 1 200 m) from the Assam Hills in India across Myanmar, Thailand, the Lao People's Democratic Republic, Viet Nam and Cambodia to southern China and the Philippines (Turnbull, Armitage

Pinus kesiya ***grows in the highlands in Southeast Asia: a natural stand on a ridge (left slope) at 1 200 to 1 300 m altitude, Chiang Mai Province, northern Thailand***

FAO/M. KASHIO

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Andy Jarvis is with Bioversity International and the International Centre of Tropical Agriculture (CIAT) in Cali, Colombia.


FAO/M. KASHIO

Pinus merkusii ***grows at lower elevations: a natural stand at 600 m altitude, Chiang Mai Province, northern Thailand***

and Burley, 1980). *P. merkusii* is found at lower elevations in the same countries, excluding China and India (Cooling, 1968), as well as in Indonesia (Sumatra), thus being the only pine species growing naturally in the Southern Hemisphere. *P. dalatensis* and *P. krempfii* are limited to the highlands of southern Viet Nam (Richardson and Rundel, 1998).

P. kesiya is planted both within and outside its natural range; it has become an important tree species for plantation forestry in several African countries in particular. *P. merkusii* is of less interest for plantation forestry because in mainland Southeast Asia the initial height growth of seedlings is delayed for several years (as the species has a so-called "grass stage" when needles take the form of clumps of grass while a robust taproot develops – considered to be a selective advantage for natural regeneration in areas where forest fires are frequent). *P. merkusii* has been used for plantations only in Indonesia as its insular populations do not have the grass stage.

P. kesiya and *P. merkusii* grow on poor, well-drained soils, often forming mixed stands with broadleaves (e.g. *Dipterocarpus*, *Quercus* and *Shorea* species). The two pine species are rather well adapted to forest fires, but frequent anthropogenic fires often prevent successful regeneration and lead to formation of open, savannah-like pine stands. However, fires may help pines occupy sites where they would otherwise be outcompeted by broadleaves (Turakka, Luukkanen and Bhumibhamon, 1982).

PREDICTING PRESENT AND FUTURE DISTRIBUTION AREAS

Climate envelope modelling is a useful tool for rapid assessment of the potential impact of climate change on the distribution of species and ecosystems. This type of modelling uses the documented geographic distribution of a species as a basis for predicting its climatic niche, i.e. the potential occurrence of the species. Future shifts of the climate niche are then estimated based on the climate projections of global circulation models.

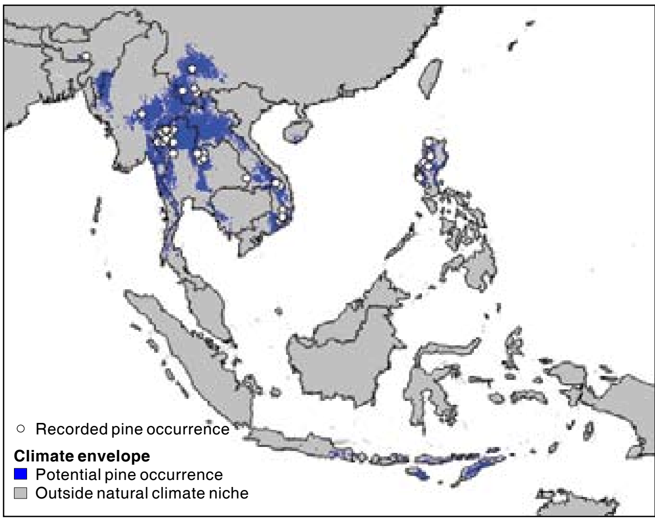
The analysis for *Pinus* species in Southeast Asia used location data for natural pine populations identified as provenances for seed collection programmes (FAO, 1970; Danish/FAO Forest Tree Seed Centre, 1973; Barnes and Keiding, 1989) and forest stands prioritized for *in situ* conservation programmes (Danida Forest Seed Centre, 2000; Razal *et al.*, 2005), as well as herbarium data that are freely accessible through the Global Biodiversity Information Facility (see www.gbif.org). The data included the locations of 46 natural *P. kesiya* populations and 50 natural *P. merkusii* populations.

The present climate of the natural pine populations was described using the 19 climate variables of Bioclim (Busby, 1991), derived from the global climate layers of the WORLDCLIM database (Hijmans *et al.*, 2005a). This database also provided information on the species' present altitudinal range. Climate projections were made for the year 2050 using the average of the predictions of two widely used global circulation models (HADCM3 and CCCMA) under a "business as usual" CO_2 emission scenario.

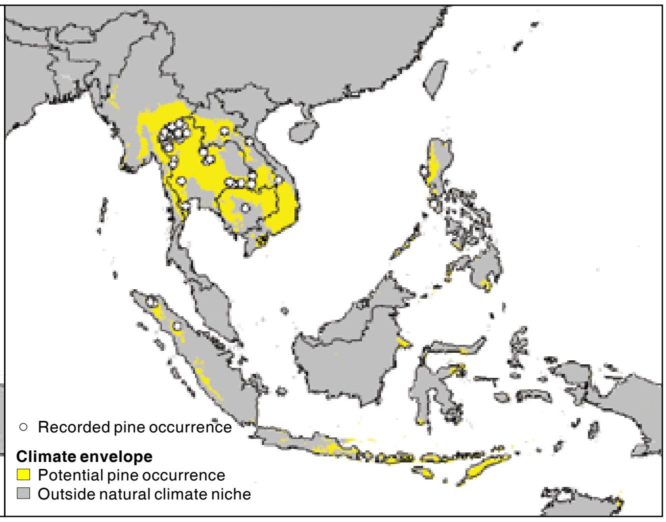
The CEM modelling program Maxent (Phillips, Anderson and Schapire, 2006) was used to elaborate the present and future climatic envelope for the natural occurrence of the two pine species. The climate envelopes were then mapped and changes or shifts in the distribution ranges were observed.

CURRENT AND POTENTIAL PINE DISTRIBUTION UNDER PRESENT CLIMATIC CONDITIONS

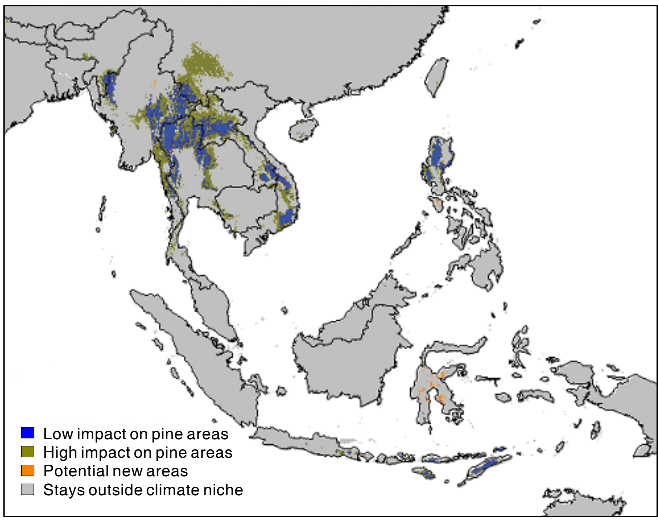
The climate envelope developed for *P. kesiya* (Figure 1) shows that in addition to the areas where natural populations have been recorded, the species



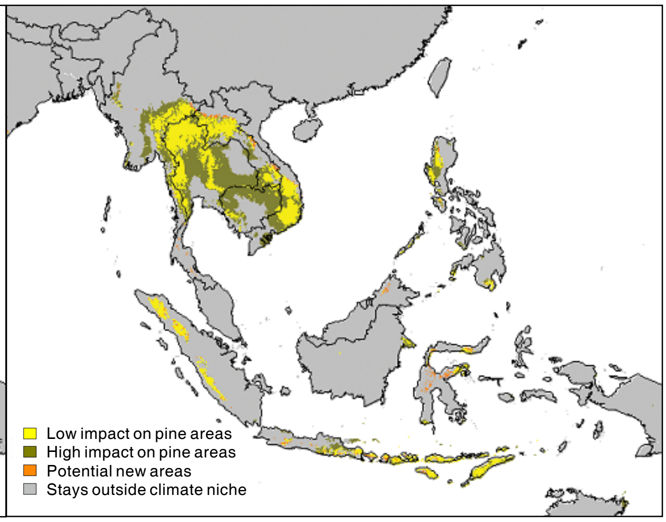
1
***Recorded and potential occurrence of* Pinus kesiya**



2
***Recorded and potential occurrence of* Pinus merkusii**



3
Climate change impact prediction for natural* Pinus kesiya *occurrence



4
Climate change impact prediction for natural* Pinus merkusii *occurrence

could potentially occur in several other locations in Myanmar, northeastern and southern Thailand, the Lao People's Democratic Republic and southwestern Cambodia. Although only one population was recorded in Myanmar, *P. kesiya* is likely to occur more abundantly in that country than available information implies. The Indonesian provinces of Java and Nusa Tenggara are outside the recorded natural distribution range of *P. kesiya* but appear to have a suitable climate for the species.

The climate envelope developed for *P. merkusii* (Figure 2) coincides with the observed distribution of the species in mainland Southeast Asia and in Sumatra. The results from CEM suggest that the climate is suitable for *P. merkusii* outside its natural geographic range in several parts of the Malay Archipelago and in northern Australia.

POTENTIAL CLIMATE CHANGE IMPACTS ON PINE DISTRIBUTION

In general few new areas in mainland Southeast Asia are expected to become suitable for the two pine species as a result of climate change (Figures 3 and 4). Lowland *P. merkusii* stands in Cambodia and Thailand are expected to be most threatened by climate alterations (Figure 4). On the other hand, the climate is predicted to become more suitable for plantations of *P. merkusii* and to lesser extent of *P. kesiya* in several parts of the Malay Archipelago.

Most of the recorded *P. kesiya* populations occur at higher altitudes, on average 1 022 m above sea level. Climate change is not expected to affect these populations significantly. *P. kesiya* populations that occur in areas characterized by high temperature seasonality are expected to become most threatened (Table 1), especially those in southern China (Figure 3). However, the impact of climate change on these populations may not be as dramatic as predicted by CEM. Provenances of *P. kesiya* from China established in trials outside the species' natural climate range in southeastern Africa and Viet Nam have performed moderately well (Costa e Silva, 2007), which suggests that these provenances are able to adapt to new climatic conditions.

P. merkusii forests already occurring in high-temperature conditions are predicted to be those most vulnerable to climate change (Table 2). The lowland provenances in eastern Thailand and northern Cambodia in particular are expected to suffer from further temperature increment (Figure 4). It can be expected that in several of these forest stands temperatures will increase beyond the tolerance range of the species, with maximum temperatures in the warmest month in 2050 predicted to be above 36°C (Table 2), a maximum temperature that will kill adult trees of this species according to FAO's Ecocrop database (see Hijmans *et al.*, 2005b). In these areas local provenances of *P. merkusii* can be expected to become degraded and eventually extinct.

IMPLICATIONS

The large potential distribution ranges of the two pine species does not necessarily mean that the pine forests can easily survive. In fact, the current distribution consists of a small number of remaining pine forests because of felling and exploitation for fuelwood. As a result, *P. merkusii* already has a vulnerable conservation status according to the criteria of the International Union for Conservation of Nature (IUCN, 2008). Climate change is an additional threat making the natural populations of this species even more susceptible to degradation and extinction.

As mentioned above, *P. merkusii* lowland provenances are predicted to be most affected by climate change. The degradation and extinction of these provenances may result in a loss of important genetic resources for plantation forestry and for reforestation activities using this species. Many *P. merkusii* lowland forest stands are isolated, and this is likely to restrict migration of lowland provenances upward to climatically better suited areas. Therefore transplantation of lowland provenances of *P. merkusii* to climatically more suitable areas might be the only alternative to conserve their genetic resources *in situ*. Similar measures have been recommended to conserve lowland provenances of *P. oocarpa* in Michoacán, Mexico (Sáenz-Romero, Guzmán-Reyna and Rehfeldt, 2006).

CEM climate change impact predictions take into account the climatic range in which a species occurs naturally at present. Since the species may be adapted to a wider range than this, these models may overestimate climate

TABLE 1. Average predicted changes of five key climate variables for *Pinus kesiya* populations in areas of low and high impact

Climate variables	Populations in areas of low impact			Populations in areas of high impact		
	Present	2050	Change	Present	2050	Change
Annual mean temperature (˚C)	21.7	23.3	1.6	22.9	24.3	1.3
Maximum temperature in warmest month (˚C)	30.4	32.7	2.3	32.0	33.9	1.9
Temperature seasonality (standard deviation of annual mean temperature x 100)	197.0	188.9	-8.1	271.3	259.3	-12.0
Annual precipitation (mm)	1754.1	1974.3	220.2	1511.0	1687.7	176.7
Precipitation in driest quarter (mm)	53.6	48.3	-5.3	60.4	56.5	-3.9

TABLE 2. Average predicted changes of five key climate variables for *Pinus merkusii* populations in areas of low and high impact

Climate variables	Populations in areas of low impact			Populations in areas of high impact		
	Present	2050	Change	Present	2050	Change
Annual mean temperature (˚C˚)	22.9	24.3	1.3	26.7	28.4	1.7
Maximum temperature in warmest month (˚C)	32.0	33.9	1.9	34.3	36.7	2.5
Temperature seasonality (standard deviation of annual mean temperature x 100)	271.3	259.3	-12.0	161.2	170.8	9.6
Annual precipitation (mm)	1511.0	1687.7	176.7	1721.7	1862.7	141.0
Precipitation in driest quarter (mm)	60.4	56.5	-3.9	35.6	32.1	-3.5

change impacts. Furthermore, several subtropical and tropical pines, including *P. kesiya*, have a high degree of genetic variation and tolerate a wide range of climates. Performance in multi-site provenance trials shows that they are adapted well to a wide range of climates Thus they may also be able to adapt to new climatic conditions in their natural habitat, even if these conditions are predicted to be unsuitable in CEM studies (van Zonneveld *et al.*, 2009).

In addition to climate, soil conditions, plant competition and other factors also influence species occurrence and are likely to be additional constraints for the present species distribution and future distribution shifts. However, as climate is considered the primary driver of future distribution changes, the CEM climate change predictions did not take these other factors into account. Furthermore, global circulation models vary considerably in their projections, and as a result CEM climate change predictions contain some uncertainty. Nevertheless, despite its limitations, CEM can be considered a useful tool for obtaining a first approximation of the potential impact of climate change on species occurrence (Pearson and Dawson, 2003).

This approach can also be used for other species and in other regions. For example, similar methods have been used to predict the effect of climate change on pine and oak (*Quercus*) species in Mexico (Gómez-Mendoza and Arriaga, 2007) and numerous tree species in the United States (Iverson *et al.*, 2008).

CONCLUSIONS

Climate envelope modelling has helped to predict which pine forests are most likely to be affected by climate change, enabling forest conservation and management programmes not only to anticipate impacts, but also to identify opportunities. Climate change is expected to favour pine plantation forestry in the Malay Archipelago, as new areas become climatically suited for *P. merkusii* establishment and to a lesser extent for *P. kesiya*.

Although these species may be able to adapt to the new climatic conditions in ways not predicted by the model, the situation for the lowland provenances of *P. merkusii* on mainland Southeast Asia seems critical as temperatures are expected to exceed the species' tolerance. If proper conservation measures are not taken, in the next decades these provenances are likely to become degraded and eventually extinct at the locations where they currently occur naturally. ◆

Bibliography

Barnes, R.D. & Keiding, H. 1989. International provenance trials of *Pinus kesiya*. *Forest Genetic Resources Information*, 17: 26–29. Rome, FAO.

Busby, J.R. 1991. BIOCLIM – a bioclimatic analysis and prediction system. *In* C.R. Margules & M.P. Austin, eds. *Nature conservation: cost effective biological surveys and data analysis*, pp. 64–68. Canberra, Australia, Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Cooling, E.N. 1968. Pinus merkusii. Fast Growing Timber Trees of the Lowland Tropics No. 4. Oxford, UK, Commonwealth Forestry Institute.

Costa e Silva, J. 2007. *Evaluation of an international series of* Pinus kesiya *provenance trials for adaptive, growth and wood quality traits*. Forest & Landscape Working Papers No. 22. Copenhagen, Denmark, Forest & Landscape Denmark.

Danida Forest Seed Centre. 2000. *Conservation of genetic resources of* Pinus merkusii *in Thailand*. Technical Note No. 58. Humlebaek, Denmark.

Danish/FAO Forest Tree Seed Centre. 1973. *Pinus merkusii* provenance collections 1972. *Forest Genetic Resources Information*, 2: 62–63.

FAO. 1970. Notes on provenance tree seed collections. *Unasylva*, 97/98: 130–132.

FAO. 2007. *State of the World's Forests 2007.* Rome.

Gómez-Mendoza, L. & Arriaga, L. 2007. Modeling the effect of climate change on the distribution of oak and pine species of Mexico. *Conservation Biology*, 21: 1545–1555.

Hijmans, R.J., Cameron, S.E, Parra, J.L., Jones, P.G. & Jarvis, A. 2005a. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25: 1965–1978.

Hijmans, R.J., Guarino, L., Jarvis, A., O'Brien, R., Mathur, P., Bussink, C., Cruz, M., Barrantes, I. & Rojas, E. 2005b. *DIVA-GIS Version 5.2 manual.* Available at: www.diva-gis.org

International Union for Conservation of Nature (IUCN). 2008. *2008 IUCN Red List of Threatened Species*. Available at: www.iucnredlist.org.

Iverson, L.R., Prasad, A.M., Matthews, S.N. & Peters, M. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. *Forest Ecology and Management*, 254: 390–406.

Pearson, R.G. & Dawson, T.E. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography*, 12: 361–371.

Phillips, S.J., Anderson, R.P. & Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modeling*, 190: 231–259.

Razal, R.A., Tolentino, E.L.T. Jr., Carandang, W.M., Nghia, N.H., Hao, P.S. & Luoma-Aho, T. 2005. Status of genetic resources of *Pinus merkusii* (Jungh et De Vriese) and *Pinus kesiya* (Royle ex Gordon) in Southeast Asia. Los Baños, the Philippines & Serdang, Malaysia, University of the Philippines Los Baños College of Forestry and Natural Resources & International Plant Genetic Resources Institute (IPGRI) Regional Office for Asia, the Pacific and Oceania.

Richardson, D.M. & Rundel, P.W. 1998. Ecology and biogeography of *Pinus*: an introduction. *In* D.M. Richardson, ed. *Ecology and biogeography of* Pinus, pp. 3–46. Cambridge, UK, Cambridge University Press.

Sáenz-Romero, C., Guzmán-Reyna, R.R. & Rehfeldt, G.E. 2006 Altitudinal genetic variation among *Pinus oocarpa* populations in Michoacán, Mexico – implications for seed zoning, conservation, tree breeding and global warming. *Forest Ecology and Management*, 229: 340–350.

Turakka, A., Luukkanen, O. & Bhumibhamon, S. 1982. Notes on *Pinus kesiya* and *P. merkusii* and their natural regeneration in watershed areas of northern Thailand. *Acta Forestalia Fennica*, No. 178.

Turnbull, J.W., Armitage, F.B. & Burley, J. 1980. Distribution and ecology of the *Pinus kesiya* complex. *In* F.B. Armitage & J. Burley, eds. Pinus kesiya, pp. 13–45. Tropical Forestry Paper 9. Oxford, UK, Commonwealth Forestry Institute.

van Zonneveld, M., Jarvis, A., Dvorak, W., Lema, G. & Leibing, C. 2009. Climate change impact predictions on *Pinus patula* and *Pinus tecunumanii* populations in Mexico and Central America. (Submitted for publication)◆

Effect of global climate change on rare trees and shrubs

M.S. Devall

Pondberry,* Lindera melissifolia *– a rare species for which climate change poses a threat

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In the past, climate has fluctuated with periods of cooler, warmer, drier or wetter weather than at present. Plants have been able to adapt, but widespread, rapid warming could be disastrous for rare trees and shrubs – i.e. those native species that are among an area's most infrequent and most in need of conservation efforts. Rare plants and rare plant communities often exist as relicts of times past, and have survived locally owing to very particular combinations of environmental conditions.

Rare forest trees and shrubs face particular conservation challenges. A drier climate could be stressful for rare plants, but a wetter climate could cause flooding. Wetlands, especially if degraded, will be vulnerable to drying out in a warmer atmosphere. Rare trees and shrubs will likely be more vulnerable to extinction as a result of warmer climate. Many rare species have characteristics that place them at risk, such as small populations, habitat specialization or limited geographic range. In the southern United States, for example, a number of rare tree and shrub species are confined to areas spanning 100 km or less in latitude, and very few have continuous distributions of more than 100 km with no disjunctions. Plants occurring in mountainous regions may find refuge by ascending in elevation, where possible. Plant communities at lower elevation are vulnerable to rising sea levels. In many areas, land development has restricted the options for rare plant species to adapt. With climate change, rare plants may also become increasingly vulnerable to invasive plant and animal species. In the absence of human intervention, many rare trees and shrubs will probably become extinct.

An example of a rare species that will likely be threatened by global climate change is pondberry (*Lindera melissifolia*) in the southeastern United States. Pondberry is a shrub up to 2 m tall that occurs in seasonally flooded wetlands and on the wet edges of sinks, ponds and depressions. The species is dioecious, and female clones are usually smaller than male clones or sometimes absent from stands. As in many clonal species, seedlings are rarely observed. The distribution and abundance of pondberry have already been affected by habitat destruction and alteration, especially timber cutting, clearing of land and local drainage or flooding of wetlands. The species was listed as endangered by the United States Fish and Wildlife Service in 1986. Many of the existing pondberry colonies are small and occupy only a portion of the apparently suitable habitat. The Lower Mississippi Alluvial Valley, in which two-thirds of the present ponderry populations occur, is one of the most endangered ecosystems in the United States. Much of the habitat suitable for pondberry dispersal is fragmented today; thus populations that die out usually will not be replaced.

Climate change and conservation of *Araucaria angustifolia* in Brazil

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Climate vulnerability mapping is used to predict areas where climate change will have drastic effects on given tree species or populations, so they can be prioritized for conservation

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The ombrophilous (high-rainfall tolerant) mixed forest of southern Brazil has a canopy dominated by Parana pine (*Araucaria angustifolia*) and is thus also referred to as *Araucaria* forest (Veloso, Rangel Filho and Lima, 1991), even though the composition of its vegetation may vary significantly according to latitude, altitude, soil and microclimate (Reitz and Klein, 1966). This forest type is found only in the Neotropics and is typical of the southern tableland.

Araucaria angustifolia forests are under considerable pressure today as they are usually located in densely populated areas. Recent and predicted climate change may present a further challenge to the future survival of these tree populations. This article describes the origin of the *Araucaria* forest and outlines how it has been influenced by climate change throughout the Cenozoic, the most recent (and ongoing) geologic era. It points out some of the limitations of current attempts to map climate vulnerability in the populations described, and considers the importance of maintaining their genetic variability to enable their adaptation to a changing climate and thus their conservation.

ABOUT *ARAUCARIA* FOREST AND *A. ANGUSTIFOLIA*

In Brazil, *Araucaria* forest occurs south of the Tropic of Capricorn between the altitudes of 50 and 1 800 m, most frequently between 500 and 1 200 m, and is surrounded by subtropical humid forest. Fragmented populations of *A. angustifolia* also occur in northeastern Argentina and southeastern Brazil (Hueck, 1953). The *Araucaria* forest covers 177 600 km^2 in Brazil (Leite and Klein, 1990) and 2 100 km^2 in Argentina (Giraudo *et al.*, 2003).

The presence of *A. angustifolia* in the Brazilian subtropical area has its origins in continental drift which resulted in the dispersion of *Araucaria* ancestors along with other vegetation. *Araucaria* fossils are distributed throughout the world, but surviving species today are found only in Australia (seven species) and South America (two species). The region of origin of *A. angustifolia* in southern Brazil is therefore uncertain. During the late Pleistocene (the era from 1.8 million to 10 000 years ago), elevation of the continental platform to altitudes that made the rainy climate suitable for *A. angustifolia* possible at this latitude allowed the formation of an ombrophilous nucleus or founder population. Subsequent geological phenomena caused this nucleus to expand and contract over time; at its largest the natural distribution reached northeastern Brazil (Veloso, Rangel Filho and Lima, 1991; Leite, 1994).

Araucaria angustifolia occurs naturally on a variety of soils, from shallow to deep and from wet to well drained. One of the main environmental features that determines its distribution, and consequently its susceptibility to climate change, is the presence of frost, which allows the species to outperform competing tree species at the higher altitudes where it thrives.

The species has been intensively exploited for timber, and the *Araucaria* forest area has also been reduced by expansion of agriculture. Even though

***Araucaria angustifolia* dominates the forest canopy at Itaimbezinho Valley, Rio Grande do Sul State, Brazil**

today *A. angustifolia* is legally protected and its harvesting for timber is prohibited by law in Brazil, the remaining areas of the species in its natural distribution areas are fragmented and scattered, with few large populations remaining. The conservation status of this forest type is considered critical. In addition, the age distribution of the remaining populations is skewed towards older age classes.

A HISTORY LINKED WITH CLIMATE CHANGE

Palaeontological studies have attempted to relate past climate to the current vegetation in the southern tableland of Brazil. It is assumed that three to four periods of severe climate fluctuations in the Cenozoic have influenced current vegetation distribution and composition. Two dry periods have occurred, a drastic drought episode in the Pleistocene and a milder one during the subsequent Holocene (which began 10 000 years ago) (Klein, 1984).

In the dry and cold period before the last glacial maximum, 50 000 years ago, the vegetation was dominated by grasslands and shrubs, with forests restricted to deep valley refuges (Ledru *et al*., 1996). From 45 000 to 33 000 years ago humidity increased, and evidence has been found of the presence of *A. angustifolia*, *Drimys brasiliensis* and *Cyathea* sp. Ombrophilous forest did not occur on the plateau, but only as small populations in refuge areas on the wetter coastal slopes and in river valleys (Ledru *et al*., 1994). Possibly between 17 000 and 8 500 years ago, the region experienced a series of climate fluctuations dominated by cold dry conditions, interrupted by a brief period of higher humidity from 13 000 to 11 000 years ago. Around 8 500 years ago, temperatures continued to be low but humidity began to return, increasing the *Araucaria* presence associated with species of the genera *Symplocos*, *Drimys*, *Lithraea*, *Podocarpus*, *Myrsine* and *Alchornea* (Ledru, 1993).

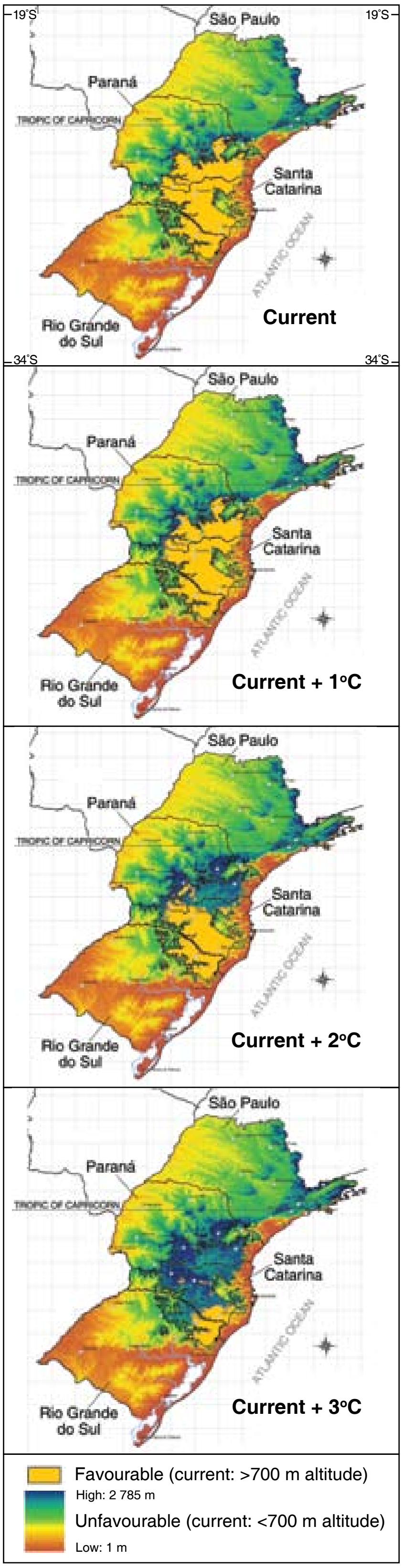
The current humid conditions returned from about 4 300 years ago (Behling, 2005). As the conditions became more steadily humid the *Araucaria* forest expanded to previous subtropical grasslands at higher altitudes. Ombrophilous forest has expanded significantly during the past 1 000 years in Paraná State and the past 1 500 years in Santa Catarina State.

CLIMATE VULNERABILITY MAPPING

In the present study, two models were used to predict the impact of different climate change scenarios on the distribution of *A. angustifolia*.

First, an envelope model was used to determine the range of favourable climatic conditions for *A. angustifolia* based on a 30-year climatic series from Brazil's southern region. Climate vulnerability mapping was used to predict the effect of 1º, 2º and 3ºC increases in temperature on the current natural distribution of *A. angustifolia*. The maps were developed based on linear regression with latitude, longitude and elevation to identify zones potentially suitable for the species under these scenarios. The maps predict a significant reduction of the area suitable for the species, indicating that with a temperature increase of 3ºC, only a small area at the highest part of the southern Brazilian tableland would be favourable (Figure 1).

Second, a regional circulation model developed by the Brazilian National Institute for Space Research (INPE) was used to generate scenarios for 2010, 2030 and 2050, based on changes in atmospheric circulation predicted by IPCC (2007). Temperature data were used to map areas suitable for *A. angustifolia*. The maps were developed using the geoprocessing program ArcGIS9. As in the first model, linear regression was used to relate temperature with latitude, longitude and elevation. This second simulation predicted less reduction in the species' distribution area (Figure 2).



1
***Araucaria angustifolia** geographic distribution in southern Brazil according to various temperature scenarios*

GENETIC VARIATION AND ADAPTATION

Understanding of the factors affecting the past and present distribution of a species is important for conservation programmes. Responses of tree species to environmental change are complex. Their ultimate survival will depend on seed dispersal and on their ability to reproduce successfully. Vulnerability can be manifested in changes in flowering and seed germination, reduced regeneration success and diminished growth rates, and is often aggravated by increased disturbance by fire and insects and increased competition from competing or exotic (introduced) vegetation. The interaction of different stress factors is difficult to predict. For *A. angustifolia*, the main stress factors are water deficit and high temperatures.

Genetic variability in adaptive traits is required for a species or tree population to withstand adverse environmental conditions. Maintenance of genetic diversity is thus important for adaptation to new environments. Population variability studies using molecular genetic tools are now enhancing understanding of the genetic diversity status of key species and tree populations. In *A. angustifolia*, genetic variation is present both between populations (Kageyama and Jacob, 1980; Shimizu and Higa, 1980; de Sousa, 2000) and within populations (de Sousa, 2000; de Sousa *et al.*, 2005; Stefenon, Gailing and Finkeldey, 2008). Seed dispersal is limited, but pollen is dispersed over relatively long distances (Bittencourt and Sebbenn, 2007). Although natural regeneration in *Araucaria* species has been reported to be poor in most areas studied, levels of diversity in regenerating areas were still considered sufficient to ensure future survival of the species (de Sousa *et al.*, 2005; Stefenon, Gailing and Finkeldey, 2008).

As trees have long life cycles, the process of adaptation to changing conditions is probably slower than the predicted rate of global climate change (Hamrick, 2004). Most of the negative genetic effects caused by decline and fragmentation of populations of *A. angustifolia* are expected to become evident only after several tree generations (de Sousa, 2000).

CONCLUSIONS

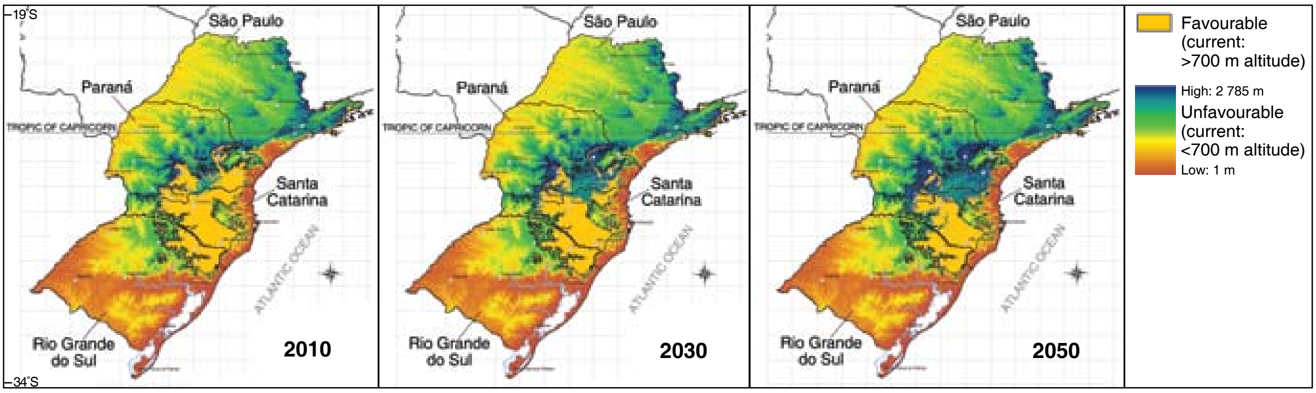
Genetic variation is necessary for adaptation of tree species and populations to environmental changes and is a precondition for conservation. More efficient strategies for conservation, whether *in situ* or *ex situ*, can be established only based on knowledge about environmental requirements and variation patterns of targeted species and forest types, combined with future climate change scenarios.

Vulnerability mapping can be useful to predict areas where climate change will have drastic effects on given tree species or populations, so they can be prioritized for germplasm collection and *ex situ* genetic conservation activities. However, more climate variables and different climate models should be used to improve future maps.

Matching information on genetic variability of tree species and populations with climate maps may help support *Araucaria* conservation programmes. Special monitoring programmes and increased attention to basic physiological research are needed for better prediction of the species' response to climate change. ◆

Bibliography

Behling, H. 2005. Late quaternary vegetation dynamics in southern and southeastern Brazil with a special focus on the *Araucaria*



2
***Araucaria angustifolia* geographic distribution in southern Brazil according to various scenarios based on global climate models**

forests. In *Resumos do 56º Congresso Nacional de Botânica*. Curitiba, Brazil, Congresso Nacional de Botânica.

Bittencourt, J.V.M. & Sebbenn, A.M. 2007. Patterns of pollen and seed dispersal in a small, fragmented population of the wind-pollinated tree *Araucaria angustifolia* in southern Brazil. *Heredity*, 99: 580–591.

de Sousa, V.A. 2000. *Population genetic studies in* Araucaria angustifolia *(Bert.) O. Ktze*. Göttingen, Germany, Cuvillier Verlag Göttingen.

de Sousa, V.A., Sebben, A.M., Hartmer, H.H. & Zihe, M. 2005. Correlated mating in populations of a dioecius Brazilian conifer, *Araucaria angustifolia* (Bert.) O. Ktze. *Forest Genetics*, 12(2): 107–119.

Giraudo, A.R., Povedano, H., Belgrano, M.J., Krauczuk, E., Pardiñas, U., Miquelarena, A., Ligier, D., Baldo, D. & Castelino, M. 2003. Biodiversity status of the interior Atlantic forest of Argentina. *In* C. Galindo-Leal & I.G. Câmara, eds. *The Atlantic forest of South America: biodiversity status, threats, and outlook*, pp. 160–180. Washington, DC, USA, Island Press.

Hamrick, J.L. 2004. Response of forest trees to global environmental changes. *Forest Ecology and Management*, 197: 323–335.

Hueck, K. 1953. Distribuição e habitat natural do Pinheiro-do Paraná (*Araucaria angustifolia*). *Boletim Faculdade de Filosofia, Ciencias e Letras da Universidade de Sao Paulo – Botânica*, 10: 1–24.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate change 2007: impacts, adaptation and vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge, UK, Cambridge University Press.

Kageyama, P.Y. & Jacob, W.S. 1980. Variação genética entre e dentro de progênies de uma população de *Araucaria angustifolia* (Bert.) O. Ktze. In *Forestry problems of the genus* Araucaria, pp. 83–86. Proceedings of the IUFRO Meeting on Forestry Problems of the Genus *Araucaria*, Curitiba, Brazil, 21–28 October 1979. Curitiba, Fundação de Pesquisas Florestais do Paraná (FUPEF).

Klein, R.M. 1984. Aspectos dinâmicos da vegetação do sul do Brasil. *Sellowia*, 36: 5–54.

Ledru, M.P. 1993. Late quaternary environmental and climatic changes in central Brazil. *Quaternary Research*, 39: 90–98.

Ledru, M.P., Behling, H., Fournier, M., Martin, L. & Servant, M. 1994. Localisation de la forêt d'*Araucaria* du Brésil au cours de l'holocène – implications paléoclimatiques. *Comptes Rendus de l'Académie des Sciences, Séries III, Sciences de la vie*, 317: 517–521.

Ledru, M.P., Braga, P.I.S., Soubies, F., Fournier, M., Martin, L., Suguio, K. & Tuerc, Q. 1996. The last 50,000 years in the Neotropics (southern Brazil): evolution of vegetation and climate. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 123: 239–257.

Leite, P.F. 1994. *As diferentes unidades fitoecológicas da região sul do Brasil – proposta de classificação*. Master's thesis, Federal University of Paraná, Curitiba, Brazil.

Leite, P.F., Klein, R.M. 1990. Vegetação. In *Geografia do Brasil*, Vol. 2, *Região Sul*, pp. 113–150. Rio de Janeiro, Brazil, *Fundação Instituto Brasileiro de Geografia* e Estatística (IBGE).

Reitz, R. & Klein, R.M. 1966. *Araucariáceas*. Itajaí, Brazil, Herbário Barbosa Rodrigues.

Shimizu, J.Y. & Higa, A.R. 1980. Variação genética entre procedências de *Araucaria angustifolia* (Bert.) O. Ketz. In *Forestry problems of the genus* Araucaria, pp. 78–82. Proceedings of the IUFRO Meeting on Forestry Problems of the Genus *Araucaria*, Curitiba, Brazil, 21–28 October 1979. Curitiba, FUPEF.

Stefenon, V.M., Gailing, O. & Finkeldey, R. 2008. Genetic structure of plantations and the conservation of genetic resources of Brazilian pine (*Araucaria angustifolia*). *Forest Ecology and Management*, 255: 2718–2725.

Veloso, H.P., Rangel Filho, A.L.R. & Lima, J.C.A. 1991. *Classificação da vegetação brasileira adaptada a um sistema universal*. Rio de Janeiro, Brazil, IBGE. ◆

Forest adaptation strategies: analysis of long-term post-fire succession in southern Siberia, Russian Federation

D.I. Nazimova,
O.V. Drobushevskaya,
G.B. Kofman and
M.E. Konovalova

An analysis of succession after natural disturbances assists in predicting the effect of climate change on the possible future composition of Siberian boreal forests in the low-mountain subtaiga.

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Forest species composition and its changes through time can be used to predict potential forest transformations under current and future climate. In the southern Siberian subtaiga in the Russian Federation, fire is the main factor determining biodiversity, regeneration and dominant tree species. The authors analysed post-fire succession over the past 350 years to predict the effect of the increase in fires that is expected to accompany climate change in this region.

Succession is the gradual supplanting of one plant community by another as conditions change, either naturally (e.g. through changing shade conditions under a tree stand) or after disturbance (e.g. fire, storm, flood, pest or disease infestation, clearcut). Most successions have a number of stages in which different collections of species dominate. The final, climax stage is reached when the species composition no longer changes with time in the absence of natural or human-caused disturbances.

Subtaiga characteristics

The mixed forests in southern Siberia are typical of low mountain landscapes in humid continental climates. They consist of Scots pine (*Pinus sylvestris*), Siberian larch (*Larix sibirica*), birch (*Betula pendula*), aspen (*Populus tremula*), Siberian fir (*Abies sibirica*) and spruce (*Picea obovata*, syn. *Picea abies* subsp. *obovata*) with a well developed herbaceous layer. These forests, classified as subtaiga, comprise the zone between "dark" (shade-tolerant) coniferous taiga (with fir, spruce and Siberian pine) and "light" (light-demanding) coniferous forest steppe (with Scots pine and larch). The forest stands are subjected to periodic fires and represent different stages of natural vegetation restoration after fire.

The subtaiga forest zone in southern Siberia (300 to 500 m above see level) differs substantially from the taiga (450 to 650 m above see level) in biodiversity, phenology and the floristic composition of the understorey. While the two zones include the same forest tree species, in the subtaiga fir and spruce are almost absent in watersheds and are located only near rivers. The subtaiga understorey is rich in herbs and grasses, but in contrast to that in the taiga, it has no moss cover.

Succession analysis

The authors reconstructed succession trajectories over the past 350 years in forests of the low mountain landscapes of southern Siberia, Russian Federation, using a combination of a chronosequence approach, detailed descriptions of 2 210 forest inventory units, data from 120 sample plots and geographic information system (GIS) technologies.

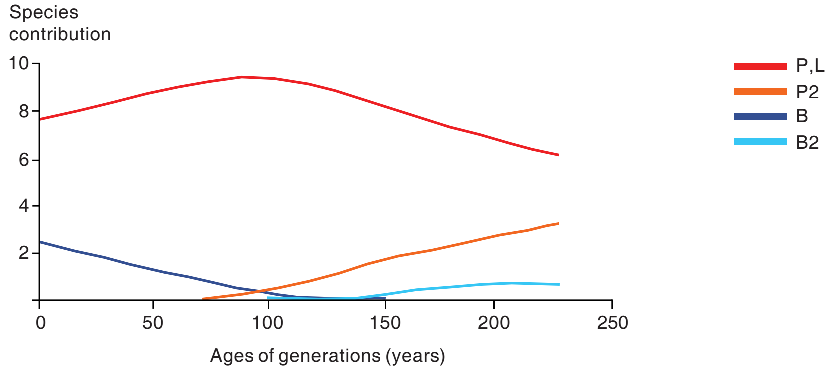
Direct methods cannot be used to reconstruct the history of mixed uneven-aged forest stands with complex vertical structure consisting of several species of different ages at every canopy layer. Construction of quasi-dynamic


O.V. DROBUSHEVSKAYA

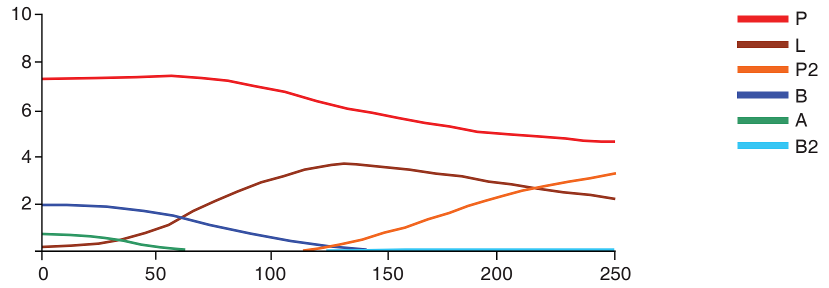
Pine-larch subtaiga with a stable mixture of birch and aspen and a well-developed layer of herbs and grasses

Long-term tree species dynamics in different forest types of the low mountain subtaiga zone (200 to 450 m above sea level)

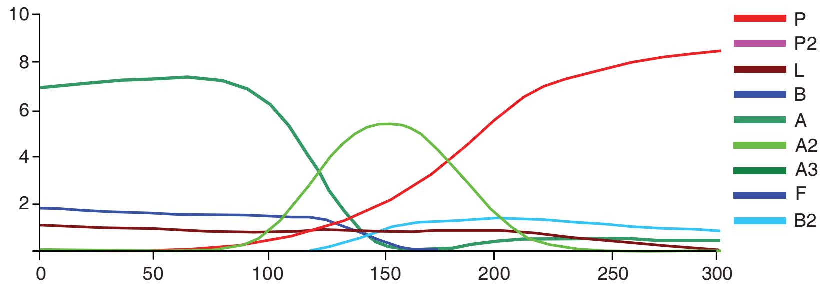
(a) *Pinus sylvestris–Caragana arborescens* stands on sunny steep and stony slopes with periodically dry soils



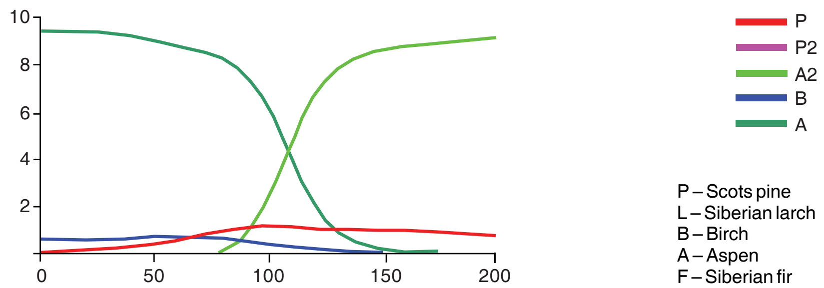
(b) *Pinus sylvestris–Spirea media–Carex macroura* stands on moist soils



(c) *Pinus sylvestris–Pteridium aquilinum* and *Crepis sibirica–Carex macroura* on moist soils on sunny slopes



(d) Mixed forest stands dominated by aspen with a well-developed layer of tall herbs and grasses *(Pteridium aquilinum, Calamagrostis arundinacea, Brachypodium pinnatum, Lilium martagon, Lathyrus gmelinii)* on concave slopes



Second and third generations of trees are indicated by number. The share of each generation of tree species (according to detailed forest inventory data) is estimated in relative units as a part of total volume.

trajectories was based on the grouping of stands of different ages growing in the same environment, with similar initial conditions and histories of development.

Twelve successional tracks or lines of succession, each comprising several succession stages, were found for the subtaiga belt with a humid continental climate. Six successional tracks were found for the higher-altitude fir taiga belt with a more humid, less continental climate.

The Figure illustrates the composition of communities and changes up to the climax stage (200 to 350 years) for different forest types of varying soil moisture and richness, reconstructed from forest inventory data. Owing to frequent surface fires these stands have not yet reached the climax stage, but the last stages of their development can be considered a quasi-climax or quasi-equilibrium state.

Birch is abundant only during the first seven to twelve decades (Figure, a–c). After its decline Scots pine and larch become the main species. Fir and spruce are sparse in most sites within the subtaiga zone.

The replacement of Siberian larch and Scots pine by Siberian fir is observed only on the border of subtaiga and fir taiga. However, this process has not reached the climax stage in the areas studied because of repeated fires; mature Scots pine stands form a sub-climax in this humid variant of low mountain subtaiga.

Among the deciduous forest stands, conditions are suitable for aspen stands on fertile and moist soils. The rich diversity of herbs in the understorey (e.g. *Carex macroura*, *Calamagrostis arundinacea*, *Vicia unijuga*) proves that the system is well adapted to fire. Aspen stands occupy a niche that is favourable for many species. The well-developed layer of herbs and grasses prevents regeneration of light-demanding coniferous tree species such as Scots pine and Siberian larch. An undergrowth of shade-tolerant conifers (Siberian fir, spruce, Siberian pine) sometimes appears under the aspen canopy, but the lack of atmospheric humidity and the periodic surface fires, especially in spring, do not allow them to dominate.

Succession trends show that under subtaiga climatic conditions, only the most fire-tolerant tree species such as Scots pine and Siberian larch will dominate, characteristically for 250 to 350 years. Siberian larch is well known as a fire-tolerant species, but in humid subtaiga it gives way to Scots pine and birch, as they produce more seeds and are therefore quick to establish instead of or under larch. Either first- or second-generation Scots pine stands prevail in the final succession stages.

Conclusions

The analysis suggests that the predicted increase in fires that will result from climate change in southern Siberia will likely result in a reduction of larch and shade-tolerant conifers in favour of Scots pine, birch and aspen, along with non-tree plant communities of bushes, grasses and herbs. The plant communities in such forests will be similar in species diversity to many communities currently existing in forest-steppe and steppe zones.

The warming and increasingly humid climate can be expected to cause changes in the composition of forest ecosystems which may not be favourable from the economic point of view. Nevertheless the ecological functions of the forest ecosystems will not decrease. Moreover, aspen and birch are excellent forest species for carbon sink creation because of their fast growth. However in the subtaiga zone fires in spring and in autumn remain the most critical factor in the survival of tree species generations.

Sustainable forest management aims to help any natural regeneration. Controlled burning may be recommended in some sites to prevent large fires and to encourage regeneration of Scots pine and larch.

Finally, management plans for plantations of Siberian pine, currently the most economically valuable tree species in the subtaiga, must take into account the increased risk of destructive surface fires and emphasize fire protection. ◆

Bibliography

Caspersen, J.P. & Pacala, S.W. 2001. Successional diversity and forest ecosystem function. *Ecological Research*, 16: 895–903.

Foster, D. & Tilman, B.L. 2000. Dynamic and static views of succession: testing the descriptive power of the chronosequence approach. *Plant Ecology*, 146(1): 1–10.

Goldammer, J.G. & Furyaev, V.V., eds. 1996. *Fire in ecosystems of boreal Eurasia*. Dordrecht, the Netherlands, Kluwer Academic Publishers.

Hytteborn, H.H., Rysin, L.P., Nazimova, D.I. & Maslov, A.A. 2005. Boreal forest of Eurasia. *In* F. Anderssen, ed. *Ecosystems of the world – coniferous forests*, pp. 23–99. Amsterdam, the Netherlands, Elsevier.

Khanina, L.G., Bobrovsky, M.V., Karjalainen, T. & Komarov, A.S. 2001. *A review of recent projects on forest biodiversity investigations in Europe including Russia*. Internal Report No. 3. Joensuu, Finland, European Forest Institute.

Mitchell, F.J.G. & Cole, E. 1988. Reconstruction of long-term successional dynamics of temperate woodland in Bialowieza Forest, Poland. *Journal of Ecology*, 86: 1042–1049.

Nazimova, D.I., Andreeva, N.M., Kofman, G.B., Nozhenkova, L.F., Polikarpov, N.P. & Stepanov, N.V. 2006. Portrait models of forest cover structural biodiversity. *In* V.K. Shumny, Yu.I. Shokin, N.A. Kolchanov & A.M. Fedotov, eds. *Biodiversity and dynamics of ecosystems: information technologies and modeling*, pp. 481–547. Novosibirsk, Russian Federation, Siberian Branch of the Russian Academy of Sciences (SB RAS). (In Russian)

Nazimova, D.I. & Polikarpov, N.P. 1996. Forest zones of Siberia as determined by climatic zones and their possible transformations under global change. *Sylva Fennica*, 30(2–3): 201–208.

Nazimova, D.I., Polikarpov, N.P., Andreeva, N.M. & Sophronov, M.A. 1997. Forest zones of Siberia and post-fire demutations in current climate. In *Proceedings of the International Boreal Forest Research Association 1997 Conference*, Duluth, Minnesota, USA, 4–7 August 1997. General Technical Report NC-209. St Paul, Minnesota, USA, United States Department of Agriculture (USDA) Forest Service North Central Research Station.

Polikarpov, N.P., Tchebakova, N.M. & Nazimova, D.I. 1986. *Climate and mountain forests of southern Siberia*. Novosibirsk, Russian Federation, Nauka. (In Russian). ◆

Predicting insect continental distributions from species physiology

J. Régnière

Knowledge about an insect species' developmental responses to key climatic factors, especially temperature, is used to predict the species' potential geographic range and performance under climate change.

J.H. GHENT/US FOREST SERVICE/BUGWOOD.ORG

The gypsy moth,* Lymantria dispar*: models of the seasonality of this introduced pest in North America predict that it will expand further north and west into Canada, where it could threaten considerable hardwood forest resources

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Much evidence is accumulating that insect distributions are changing in unprecedented ways. Alterations in the Earth's climate are providing mobile insect species with increasingly hospitable habitats, and increasing global commerce is expanding opportunities for mobile species to colonize new habitats.

This article describes potential impacts of climate change on forest insect species and an approach for predicting their distributions based on their known physiological responses to specific weather factors. The modelling is based primarily on developmental responses, as these determine climates under which an insect can achieve a stable, adaptive seasonality. Models can also take into account other weather influences such as cold tolerance. Three examples are given from North America: the native spruce budworm (*Choristoneura fumiferana*); the introduced, invasive gypsy moth (*Lymantria dispar*); and the native mountain pine beetle (*Dendroctonus ponderosae*).

These studies predict that the distribution of most insect species will shift towards the poles and to higher elevations with predicted climate change, and that temperate regions will bear the main burden of these shifts. Distribution shifts may be good or bad, depending on the species and the point of view; but the models suggest that a warmer world is not necessarily a world with more pests.

CLIMATE CHANGE IMPACTS ON FOREST INSECTS

Insects constitute the most diverse form of animal life in terrestrial ecosystems. Most species are innocuous and essential components of natural ecosystems. Because they are cold-blooded, the rates of key physiological processes in their life cycles are determined by environmental conditions, especially temperature and precipitation. In general they have short generation times, high fecundity and high mobility (either through their own faculties or aided by wind, animals and humans). The effects of climate change on forest insects (reviewed in Moore and Allard, 2008) must be considered in the context of increasing international trade and changing land-use patterns.

The fossil record suggests that previous episodes of rapid global warming led to increased levels of insect herbivory (Currano *et al*., 2008). Similarly, insect herbivory levels are currently increasing (DeLucia *et al*., 2008), for example in the birch forests of northern Europe (Wolf, Kozlov and Callaghan, 2008). The reasons include lower plant defences and higher plant nutritional value in the presence of increased CO_2 and O_3 (Kopper and Lindroth, 2003) and altered seasonal synchrony between plants, insect herbivores and their natural enemies (van Asch and Visser, 2007; Stireman *et al*., 2005).

Many insects are sensitive to extreme weather events (droughts, heat waves, cold spells). As a result of climate change and deforestation, tropical environments that harbour the bulk of Earth's biodiversity could very well become too hot, dry or fragmented for many insect species to persist (Williams, Bolitho and Fox, 2003). Species that exhibit highly evolved host plant interactions or inhabit microhabitats are at high risk of extinction, especially in tropical areas (Lewis, 2006).

Changing distributions

The climates of temperate and subarctic regions are becoming increasingly hospitable to plant and insect life, raising concerns about the behaviour of indigenous species and about the risk of invasion by exotic species, which could result in disruption of normal ecosystem functions. Many temperate-zone insect species have shifted their distributions in response to recent climate change. Examples are the pine processionary moth (*Thaumetopoea pityocampa*) in Europe (Battisti *et al*., 2006), winter moth (*Operophtera brumata*) and autumnal moth (*Epirrita autumnata*) in Scandinavia (Jepsen *et al*., 2008) and southern pine beetle (*Dendroctonus frontalis*) in North America (Tran *et al*., 2007). Some species that have historically been constrained in their distribution by geographical barriers such as mountain ranges or large bodies of water are likely to overcome these barriers and suddenly expand their range. For example, increased movements of warm air masses towards high latitudes have caused recent influxes of diamondback moth (*Plutella xylostella*) on the Norwegian islands of Svalbard in the Arctic Ocean, 800 km north of the edge if its current distribution in the western Russian Federation (Coulson *et al*., 2002).

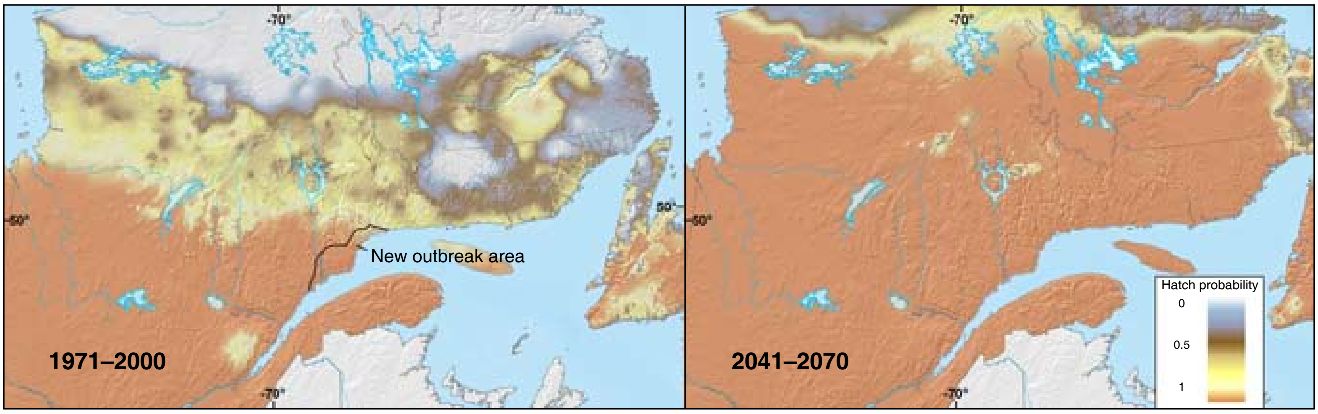
The fate of specific insect species depends on their degree of specialization (host and habitat range), their mobility and the factors constraining their distribution. Specialist butterfly species are declining in abundance in the United Kingdom, while generalist species are increasing (Thomas, 2005; Franco *et al*., 2006). Insect species richness is increasing in the cool habitats of the planet (Andrew and Hughes, 2005). Butterfly species found throughout the United Kingdom are decreasing most rapidly in the south, while species with a southerly distribution are expanding northward (Conrad *et al.*, 2004). Thus, the geographical range of insect species may be shifting by simultaneous expansion at the upper end and contraction at the lower end of their latitude and altitude limits (Parmesan *et al.*, 1999).

Insect species are also changing their genetic makeup in response to climate change. While genetic change is a normal process in nature, exceptionally rapid alterations have been observed over short periods (in the order of a decade) in morphology related to flight capacity (Hill, Thomas and Blakeley, 1999; Thomas *et al.*, 2001), life history strategies, diapause (dormancy) induction (Burke *et al.*, 2005), developmental physiology (Rank and Dahlhoff, 2002) and cold tolerance (Calosi *et al.*, 2008) in species that are changing their range.

Outbreak frequency

Conclusive evidence of changes in outbreak frequencies among forest insect pests in response to climate change is rare, as it must be based on long historical records and adequate knowledge of each insect's population dynamics. Considerable information has linked drought stress due to climate change and extensive damage by insects to pinyon pine (*Pinus* spp.) in the southwestern United States (Trotter, Cobb and Whitham, 2008). There is evidence that the regular (8- to13-year) outbreak cycles of larch budmoth (*Zeiraphera diniana*) in Switzerland have stopped since the early 1970s (Esper *et al.*, 2007). Outbreaks of spruce budworm (*Choristoneura* spp.) in eastern Canada seem to have increased in frequency and severity over the past 200 years (Simard, Morin and Lavoie, 2006). Climate change can affect the behaviour of insect populations in their current range by altering the ecological interactions that regulate them. These effects are difficult to predict in large part because the population dynamics of few species are sufficiently understood (Harrington, Fleming and Woiwod, 2001). Even for the most studied species, such as the spruce budworm in North America, the complexity of ecological interactions involved is almost overwhelming (Eveleigh *et al.*, 2007).

1
Probability of spruce budworm egg hatch prior to the onset of winter in Quebec, Canada under current and predicted future climate

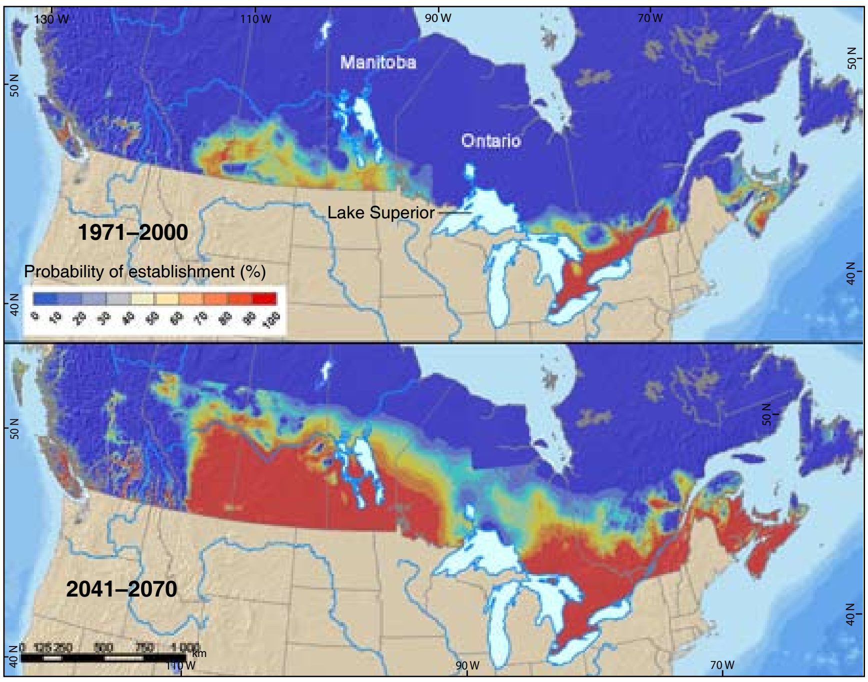


PREDICTING GEOGRAPHICAL DISTRIBUTIONS

Global spread of harmful forest pest species is a possible consequence of climate change. Because of the diverse and complex responses of insects to climatic factors, it is difficult to make general predictions. Generic modelling tools such as BioSIM (Régnière and St-Amant, 2008) use available knowledge about the responses of particular species (usually pests) to key climatic factors to predict their potential geographic range and performance. These models focus mainly on factors that determine the insect's seasonality and those that affect its survival during the harshest season (usually winter). They are based on the idea that the insect's most fundamental requirement is to complete the life cycle in a well-adapted seasonal pattern, with adequate synchrony between essential resources such as host plants for food and shelter and the life stages that require them. If a species cannot satisfy this basic viability requirement generation after generation under a specific climate, it cannot persist in that environment.

Once a seasonality model is available for an insect species, its distribution can be predicted by mapping climates that produce viable seasonality with more or less certainty, and overlaying the distribution of resources vital to (or most at risk from) that species. Predictions can be further refined by also considering the probability of survival under extreme climatic conditions (based for example on tolerance to cold or heat). This approach has been applied to three species of importance to North American forests, using climate normals (averages and variances measured over standard 30-year intervals) for the periods 1971–2000 and 2041–2070 based on a conservative climate change scenario driven by a 1 percent per year increase in atmospheric CO_2 (Logan, Régnière and Powell, 2003).

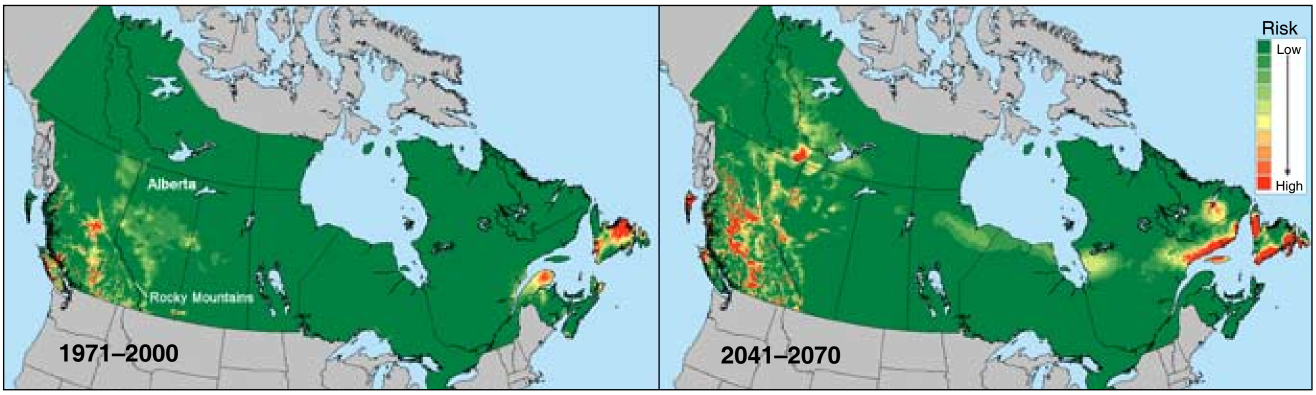
2
Probability of gypsy moth establishment in Canada under current and predicted future climate, based on adequate seasonality



Three North American examples

The spruce budworm *Choristoneura fumiferana* is a native defoliator of conifers that ranges from the West to East Coasts in Canada and through the northern United States from Minnesota in the Midwest to Maine on the East Coast. The northern part of its current distribution is generally limited by the range of its host plants. However, there are areas in eastern Canada where it is limited by adverse climate and where climate change is likely to allow it to thrive. The analysis used a detailed process-based model of the insect's developmental responses to temperature. Winter cold is not a particularly important source of mortality for spruce budworm; this species, which is strictly univoltine (i.e. has one brood per year), spends winter in a deep diapause in early larval development. Where host plants are available, its northern and high altitude limit is set by summers that are too cool for eggs to hatch before winter, in time for larvae to find appropriate winter shelter. Thus, the probability of egg hatch before the onset of winter is a good estimator of the insect's likelihood of persisting in a given location. The models depict accurately the insect's current distribution in eastern Canada. Under climate change, this distribution is expected to creep towards more northerly latitudes and higher altitudes, to be limited only by the availability of suitable host trees (Figure 1). There is evidence that this is already occurring, as a new outbreak is developing at unusually high latitudes on the north shore of the Saint Lawrence River in Quebec. More severe and prolonged outbreaks can therefore be expected in areas that have usually escaped such damage in the past because of inclement weather.

The gypsy moth (*Lymantria dispar*) was introduced from Europe to the northeastern United States in 1869 and has spread west and south in the United States and north into Canada where it has now reached its northern limit set by adverse climatic conditions. Currently, the gypsy moth is confined to the east of Lake Superior (Figure 2). A model of the



3
Risk of mountain pine beetle having a univoltine (one-brood) life cycle and high winter survival in Canada under recent and predicted future climate

insect's seasonality was used to predict the probability of its establishment in Canada (Régnière, Nealis and Porter, 2009). The model predicted that this species, which is highly polyphagous (i.e. has many host plants), will threaten considerable hardwood forest resources as climate change allows it to expand further north and west into Canada. It is estimated that the proportion of Canada's deciduous forests at risk of damage by gypsy moth will grow from the current 15 percent to more than 75 percent by 2050. Much of the management strategy to reduce this risk involves monitoring and control west of Lake Superior, which has been a geographical barrier to the insect's northern spread route between Ontario and Manitoba, in conjunction with the Slow the Spread programme in the midwestern United States to prevent spread from the south.

The mountain pine beetle, *Dendroctonus ponderosae*, is an indigenous North American bark beetle that has been confined to the west of the continent by the Rocky Mountains and the Great Plains geographical barriers. Considerable knowledge of the insect's physiological responses to temperature is available, both in terms of development (Bentz, Logan and Amman, 1991) and cold tolerance (Régnière and Bentz, 2007). Models were used to determine the area in Canada that is climatically most suitable to this insect. Exactly one generation per year is ideal for this diapause-free species. Risk maps developed for the country overlay the probabilities that the insect can achieve an adaptive seasonality and that it can survive the extreme cold of the Canadian winters, both under current and future climates (Figure 3). These maps suggest that Canada east of the Rocky Mountains will remain inhospitable to this insect well into the future, except for parts of northwestern Alberta and the Atlantic seaboard. However, the risk of mountain pine beetle outbreaks in the western part of the country is likely to increase dramatically towards higher latitudes and altitudes, while decreasing at lower latitudes and altitudes. This information, combined with knowledge of the susceptibility of the various pine (*Pinus*) species in Canada's boreal forest, helped Canada devise a risk-based strategy for managing an unprecedented outbreak of mountain pine beetle in British Columbia and Alberta (Nealis and Peter, 2008) [Ed. note: see article by Konkin and Hopkins, this issue].

CONCLUSIONS

The literature points to a loss of insect biodiversity in the tropical areas of the planet, as highly specific species face the disappearance of suitable climates and hosts. At middle latitudes, distribution shifts towards higher latitudes and altitudes seem to be prevalent, especially in highly mobile and polyphagous species.

Detailed models of the responses to climate of each insect species are needed to predict distribution changes with any accuracy. However, it seems difficult to make general predictions about the responses of major forest insect pest species from the point of view of outbreak severity and frequency in their current ranges. There is an increasing risk of "invasion" into increasingly hospitable temperate ecosystems by the more mobile species. However, models indicate that insect distributions should not be expected to expand, but rather to shift towards higher latitudes and altitudes. Thus a warmer world does not necessarily imply a more pestilent world. ◆

Bibliography

Andrew, N.R. & Hughes, L. 2005. Diversity and assemblage structure of phytophagous Hemiptera along a latitudinal gradient: predicting the potential impacts of climate change. *Global Ecology and Biogeography*, 14: 249–262.

Battisti, A., Stastny, M., Buffo, E. & Larsson, S. 2006. A rapid altitudinal range expansion in the pine processionary moth produced by the 2003 climatic anomaly. *Global Change Biology*, 12: 662–671.

Bentz, B.J., Logan, J.A. & Amman, G.D. 1991. Temperature-dependent development of the mountain pine beetle (Coleoptera: Scolytidae) and simulation of its phenology. *The Canadian Entomologist*, 123: 1083–1094.

Burke, S., Pulin, A.S., Wilson, R.J. & Thomas, C.D. 2005. Selection of discontinuous life-history traits along a continuous thermal gradient in the butterfly *Aricia agestis*. *Ecological Entomology*, 30: 613–619.

Calosi, P., Bilton, D.T., Spicer, J.I. & Atfield, A. 2008. Thermal tolerance and geographical range size in the *Agabus brunneus* group of European diving beetles (Coleptera: Dytiscidae). *Journal of Biogeography*, 35: 295–305.

Conrad, K.F., Woiwod, I.P., Parsons, M., Fox, R. & Warren, M.S. 2004. Long-term population trends in widespread British moths. *Journal of Insect Conservation*, 8: 119–136.

Coulson, S.J., Hodkinson, I.D., Webb, N.R., Mikkola, K., Harrison, J.A. & Pedgley, D.E. 2002. Aerial colonization of high Arctic islands by invertebrates: the diamondback moth *Plutella xylostella* (Lepidoptera: Yponomeutidae) as a potential indicator species. *Diversity and Distributions*, 8: 327–334.

Currano, E.D., Wilf, P., Wing, S.L., Labandeira, C.C., Lovelock, E.C. & Royer, D.L. 2008. Sharply increased insect herbivory during the paleocene-eocene thermal maximum. *Proceedings of the National Academy of Sciences*, 105: 1960–1964.

DeLucia, E.H., Casteel, C.L., Nabity, P.D. & O'Neill, B.F. 2008. Insects take a bigger bite out of plants in a warmer, higher carbon dioxide world. *Proceedings of the National Academy of Sciences*, 105: 1781–1782.

Esper, J., Büntgen, U., Frank, D.C., Nievergelt, D. & Liebhold, A. 2007. 1200 years of regular outbreaks in alpine insects. *Proceedings of the Royal Society Series B*, 274: 671–679.

Eveleigh, E.S., McCann, K.S., McCarthy, P.C., Pollock, S.J., Lucarotti, C.J., Morin, B., McDougall, G.A., Strongman, D.B., Huber, J.T., Umbanhowar, J. & Faria, L.B.D. 2007. Fluctuations in density of an outbreak species drive diversity cascades in food webs. *Proceedings of the National Academy of Sciences*, 104: 16976–16981.

Franco, A.M.A., Hill, J.K., Kitschke, C., Collingham, Y.C., Roy, D.B., Fox, R., Huntley, B. & Thomas, C.D. 2006. Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. *Global Change Biology*, 12(8): 1545–1553.

Harrington, R., Fleming, R.A. & Woiwod, I.P. 2001. Climate change impacts on insect management and conservation in temperate regions: can they be predicted? *Agricultural and Forest Entomology*, 3: 233–240.

Hill, J.K., Thomas, C.D. & Blakeley, D.S. 1999. Evolution of flight morphology in a butterfly that has recently expanded its geographic range. *Oecologia*, 121: 165–170.

Jepsen, J.U., Hagen, S.B., Ims, R.A. & Yoccoz, N.G. 2008. Climate change and outbreaks of the geometrids *Operophtera brumata* and *Epirrita autumnata* in subarctic birch forest: evidence of a recent outbreak range expansion. *Journal of Animal Ecology*, 77: 257–264.

Kopper, B.J. & Lindroth, R.L. 2003. Effects of elevated carbon dioxide and ozone on the phytochemistry of aspen and performance of an herbivore. *Oecologia*, 134: 95–103.

Lewis, S.L. 2006. Tropical forests and the changing earth system. *Philosophical transactions of the Royal Society B*, 361: 195–210.

Logan, J.A., Régnière, J. & Powell, J.A. 2003. Assessing the impact of global warming on forest pest dynamics. *Frontiers of Ecology and the Environment*, 1(3): 130–137.

Moore, B. & Allard, G. 2008. *Climate change impacts on forest health.* Forest Health and Biosecurity Working Paper FBS/34E. Rome, FAO.

Nealis, V. & Peter, B. 2008. *Risk assessment of the threat of mountain pine beetle to Canada's boreal and eastern pine forests*. Information Report BC-X-417. Victoria, British Columbia, Canada, Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre.

Parmesan, C., Ryrholm, N., Stefanescu, C., Hill, J.K., Thomas, C.D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., Tammaru, T., Tennent, W.J., Thomas, J.A. & Warren, M. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature*, 399: 579–583.

Rank, N.E. & Dahlhoff, E.P. 2002. Allele frequency shifts in response to climate change and physiological consequences of allozyme variation in a montane insect. *Evolution*, 56: 2278–2289.

Régnière, J. & Bentz, B. 2007. Modeling cold tolerance in the mountain pine beetle, *Dendroctonus ponderosae*. *Journal of Insect Physiology*, 53: 559–572.

Régnière, J., Nealis, V. & Porter, K. 2009. Climate suitability and management of the gypsy moth invasion into Canada. *Biological Invasions*, 11: 135–148.

Régnière, J. & St-Amant, R. 2008. *BioSIM 9 user's manual*. Information Report LAU-X-134. Quebec, Canada, Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre.

Simard, I., Morin, H. & Lavoie, C. 2006. A millenial-scale reconstruction of spruce budworm abundance in Saguenay, Québec, Canada. *The Holocene*, 16: 31–37.

Stireman, J.O. III, Dyer, L.A., Janzen, D.H., Singer, M.S., Lill, J.T., Marquis, J.R., Ricklefs, R.E., Gentry, G.L., Hallwachs, W., Coley, P.D., Barone, J.A., Greemey, H.F., Connahs, H., Barbosa, P., Morais, H.C. & Diniz, I.R. 2005. Climatic unpredictability and parasitism of caterpillars: implications of global warming. *Proceedings of the National Academy of Sciences*, 102: 17384–17386.

Thomas, C.D., Bodsworth, E.J., Wilson, R.J., Simmons, A.D., Davies, Z.G., Musche, M. & Conradt, L. 2001. Ecological and evolutionary processes at expanding range margins. *Nature*, 411: 577–581.

Thomas, J.A. 2005. Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups.

Philosophical Transactions of the Royal Society B, 360: 339–357.

Tran, J.K., Ylioja, T., Billings, R.F., Régnière, J. & Ayres, M.P. 2007. Impact of minimum winter temperatures on the population dynamics of *Dendroctonus frontalis*. *Ecological Applications*, 17: 882–899.

Trotter, R.T. III, Cobb, N.S. & Whitham, T.G. 2008. Arthropod community diversity and trophic structure: a comparison between extremes of plants stress. *Ecological Entomology*, 33: 1–11.

van Asch, M. & Visser, M.E. 2007. Phenology of forest caterpillars and their host trees: the importance of synchrony. *Annual Review of Entomology*, 52: 37–55.

Williams, S.E., Bolitho, E.E. & Fox, S. 2003. Climate change in Australian tropical rainforests: an impending environmental catastrophe. *Proceedings of the Royal Society of London B*, 270: 1887–1892.

Wolf, A., Kozlov, M.V. & Callaghan, T.V. 2008. Impact of non-outbreak insect damage on vegetation in northern Europe will be greater than expected during a changing climate. *Climatic Change*, 87: 91–106. ◆

Climate-induced forest dieback: an escalating global phenomenon?

C.D. Allen

An introduction to emerging global patterns of climate-induced forest mortality.

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Forests, which today cover 30 percent of the world's land surface (FAO, 2006), are being rapidly and directly transformed in many areas by the impacts of expanding human populations and economies. Less evident are the pervasive effects of ongoing climatic changes on the condition and status of forests around the world. Recent examples of drought and heat-related forest stress and dieback (defined here as tree mortality noticeably above usual mortality levels) are being documented from all forested continents, making it possible to begin to see global patterns. This article introduces these patterns and considers the possibility that many forests and woodlands today are at increasing risk of climate-induced dieback. A more comprehensive article (Allen *et al.*, 2009) addresses this topic in considerably greater detail.

While climate events can damage forests in many ways ranging from ice storms to tornadoes and hurricanes, the emphasis here is on climatic water stress, driven by drought and warm temperatures.

CLIMATE AS A DRIVER OF FOREST GROWTH AND MORTALITY

The Earth's climate is recognized to be undergoing significant human-caused changes, with global mean temperatures now outside the historic range of at least the past 1 300 years (IPCC, 2007). Markedly greater shifts in climatic patterns are projected for the coming decades in many regions, including much warmer temperatures and altered precipitation patterns that drive the availability of water to plants.

Since most of the world's forests are found in areas where temperature, light or nutrients limit tree growth and productivity, recent global warming, changes in atmospheric composition (i.e. increased concentrations of nitrogen compounds and CO_2 from massive societal emissions) and local increases in sunlight and precipitation have benefited the growth of many forests in recent decades, when and where water has not been limiting (Boisvenue and Running, 2006).

On the other hand, about one-third of the Earth's land is currently too dry to support tree growth, and significant areas of forest and woodland grow in marginal climate zones where net primary vegetation productivity is strongly water limited (Boisvenue and Running, 2006). Forests in such semi-arid regions may display substantial growth declines or increases in mortality in response to droughts or warming temperatures (e.g. Peñuelas, Lloret and Montoya, 2001), as do tree species at the drier edges of their range of distribution (e.g. Jump, Hunt and Peñuelas, 2006).

Growth and mortality in wetter forests throughout the globe, however, from tropical moist forests to boreal systems, are also highly sensitive to drought (Clark, 2004; Nepstad *et al.*, 2007; Soja *et al.*, 2007). Temperate forests growing on productive sites may exhibit major growth declines, high levels of mortality and delayed multi-year effects from extreme drought and heat stress, as observed throughout Europe from the 2003 drought and heat wave (Ciais *et al.*, 2005; Breda *et al.*, 2006). Warmer temperatures alone can increase forest water stress independent of precipitation amount (Barber, Juday and Finney, 2000; Angert *et al.*, 2005). As such, it is not apparent that any forests globally are safe from the impacts of drought.

Tree mortality commonly involves multiple, interacting factors, ranging from drought to insect pests and diseases, often making the determination of a single cause unrealistic. Abiotic stress factors, however, commonly underlie forest health problems, with climate stresses thought to be a primary factor triggering many extensive forest insect and disease outbreaks (Desprez-Loustau *et al.*, 2006; Raffa *et al.*, 2008).

Climate-induced water stress may directly cause tree mortality through short-term acute effects such as irreversible disruption of water columns within tree stems and leaves (cavitation). Tree species vary widely in their resistance and vulnerability to cavitation, a key determinant of drought resistance. When subject to water stress, trees minimize the risk of cavitation through stomatal closure, which reduces water loss and subsequent tension within the xylem. Stomatal closure comes at a cost, however, as it prevents CO_2 diffusion into the foliage, thereby reducing photosynthesis. Chronic water stress over long periods will weaken and ultimately kill trees, either directly through carbon starvation or indirectly through the attacks of pests such as bark beetles which overwhelm the diminished defences of such chronically starved trees (McDowell *et al.*, 2008). Climatic conditions also directly affect the population dynamics of forest insects and fungal pathogens (e.g. Hicke *et al.*, 2006). Thus, some massive outbreaks of tree-killing forest insects may be attributed to climate drivers (Raffa *et al.*, 2008). Regardless of the exact mechanism, dieback is often a non-linear process; it can emerge abruptly at a regional scale when climatic conditions exceed a tree species' physiological thresholds of tolerance or trigger outbreaks of insect pests (Allen, 2007).

Many reports link increased forest mortality to various combinations of notable dry and/or hot conditions, such as drought in the tropics from severe El Niño events in 1988 and 1997–1998, the persistent warming and widespread drought over much of western North America since the 1990s, and the extreme heat wave and drought of summer 2003 in western Europe.

Example of drought-related mortality worldwide

Region/country	Forest type
Africa	
Algeria	*Cedrus atlantica*
Namibia	*Aloe dichotoma*
Senegal	*Acacia*, *Cordyla*, *Nauclea* and *Sterculia* species
South Africa	*Dichrostachys*, *Pterocarpus* and *Strychnos* species in the northeast
Uganda	*Uvariopsis* and *Celtis* species in tropical moist forest
Asia and the Pacific	
Australia	*Eucalyptus* and *Corymbia* species in the northeast
China	*Pinus tabulaeformia* in east and central regions, *Pinus yunnanensis* in the southwest
India	*Acacia*, *Terminalia* and *Emblica* species in the northwest
Malaysia	Dipterocarpaceae in tropical moist forests in Borneo
Republic of Korea	*Abies koreana*
Russian Federation	*Picea* and *Pinus* species in temperate and boreal forests of Siberia
Europe	
France	*Abies*, *Fagus*, *Picea*, *Pinus* and *Quercus* species
Greece	*Abies alba* in the north
Norway	*Picea abies* in the southeast
Russian Federation	*Picea obovata* in the northwest
Spain	*Fagus*, *Pinus* and *Quercus* species
Switzerland	*Pinus sylvestris*
Latin America and the Caribbean	
Argentina	*Austrocedrus* and *Nothofagus* species in Patagonia
Brazil	Atlantic tropical semi-deciduous forest in the southeast
Costa Rica	Tropical moist forest
Panama	Tropical moist forest
Near East	
Turkey	*Pinus* and *Quercus* species in the central region
Saudia Arabia	*Juniperus procera*
North America	
Canada	*Acer*, *Picea*, *Pinus* and *Populus* species
United States	*Abies*, *Fraxinus*, *Juniperus*, *Picea*, *Pinus*, *Populus*, *Pseudotsuga* and *Quercus* species

Source: Allen *et al.*, 2009 (where complete references can be found).

GLOBAL PATTERNS OF RECENT FOREST DIEBACK

Forest mortality associated with drought has been documented recently from all wooded continents (Figure, p. 46) and from diverse forest types and climatic zones. Forest dieback is commonly reported near the geographic or elevational margins of a forest type or tree species (Jump, Hunt and Peñuelas, 2006), presumably near its historic thresholds of climatic suitability, where the most sensitive response to climate fluctuations would be expected.

Some examples of forest mortality driven by climatic water and heat stress since 1970, based on a global review of more than 120 documented examples (Allen *et al.*, 2009), are presented in the Table. While forest dieback is commonly noted in semi-arid regions where trees are near the physiological limits of dryness for woody plant growth (e.g. Fensham, Fairfax and Ward, 2009), it is clear that climate-induced drought and heat stress have the potential to cause forest dieback across a broad range of forest and woodland types around the world. Examples are particularly well documented from southerly parts of Europe (Peñuelas, Lloret and Montoya, 2001; Breda *et al.*, 2006) and in temperate and boreal forests of western North America, where background mortality rates have increased rapidly in recent decades (van Mantgem *et al*., 2009) and widespread death of many tree species in multiple forest types has affected well over 10 million hectares since 1997 (Breshears *et al*., 2005; Raffa *et al.*, 2008).

CONSEQUENCES OF BROAD-SCALE FOREST MORTALITY

Assessing the potential for, and consequences of, extensive climate-induced forest dieback is fundamentally important because trees grow relatively slowly but can die quickly. A 100-year-old tree may be killed by severe drought within a few months to a few years. As a result, drought-triggered forest mortality can result in rapid ecosystem changes over huge areas, far more quickly than the gradual transitions that occur from tree regeneration and growth. Land-use impacts such as anthropogenic burns and forest fragmentation, interacting with climate-induced forest stress, are likely to amplify forest dieback in some regions, for example the Amazon Basin (Nepstad *et al.*, 2008). If current forest ecosystems are forced to adjust abruptly to new climate conditions through massive forest dieback, many pervasive and persistent ecological and social effects will result from the loss of forest products and ecosystem services – including sequestration of atmospheric carbon.

One consequence of substantial forest dieback is redistribution of within-ecosystem carbon pools and rapid losses of carbon back to the atmosphere. For instance, climate-driven effects of forest dieback, insect and disease mortality and fire impacts have recently turned Canada's temperate and boreal forests from a net carbon sink into a net carbon source (Kurz *et al.*, 2008). Similarly, it is possible that "widespread forest collapse via drought" could transform the world's tropical moist forests from a net carbon sink into a large net source during this century (Lewis, 2005).

Given the potential risks of climate-induced forest dieback, increased management attention to adaptation options for enhancing forest resistance and resilience to projected climate stress can be expected, for example thinning stand densities to reduce competition, selection for different genotypes (e.g. drought resistance) or translocation of species to match expected climate changes.

FOREST DIEBACK – AN EMERGING GLOBAL TREND?

Foresters and ecologists have long known that climate stress has major effects on forest health. Awareness of, and interest in, climate-induced forest dieback is not new (Auclair, 1993; Ciesla and Donaubauer, 1994). It is known that natural climate variation historically triggered episodes of widespread forest mortality (Swetnam and Betancourt, 1998). So, one might ask, is anything new or different occurring now? Certainly the Earth is currently experiencing substantial, rapid, directional global climate change driven by major and pervasive human alterations of the Earth's atmosphere, land surface and waters (IPCC, 2007). Concurrent with these changes, climate-related forest mortality is apparently increasing in many parts of the world. While the available evidence is not yet conclusive, it is possible that the increasing reports of dieback represent just the beginning of globally significant increases in problems associated with forest health and dieback. Given the dieback problems already reported under relatively modest recent increases in global mean temperature (about 0.5ºC since 1970) and drying climate in some areas (e.g. Seager *et al.*, 2007), far greater chronic forest stress and mortality risk could be expected because much greater increases in mean temperature (about 2º to 4ºC globally, and more in some areas) and significant long-term regional drying in some places are projected to occur by 2100 (IPCC, 2007). Beyond changes in mean climate conditions, other climate changes such as extreme droughts, elevated maximum temperatures and longer-duration heat waves, which are projected to increase in frequency and severity (IPCC, 2007), might be expected to exacerbate forest dieback.

A number of information gaps and scientific uncertainties currently limit the conclusions that can be drawn about trends in forest mortality and the predictions that can be made about future climate-induced forest dieback. First, despite many national and even regional forest monitoring efforts, there is an absence of adequate global data on forest health status (FAO, 2006). Reliable long-term, global-scale forest health monitoring, combining remote-sensing and ground-based measurements, is needed to determine the status and trends of forest stress and mortality on the planet accurately, as well as to understand ecosystem responses after dieback events.

Second, adequate quantitative knowledge of the physiological thresholds of individual tree mortality from chronic or acute water stress is available for only a few tree species (McDowell *et al.*, 2008), and associated temperature sensitivities are largely unknown. Further, there is little detailed understanding about the place-specific sequences and ranges of mean and extreme climatic conditions that can trigger species-specific tree mortality in forests on real landscapes

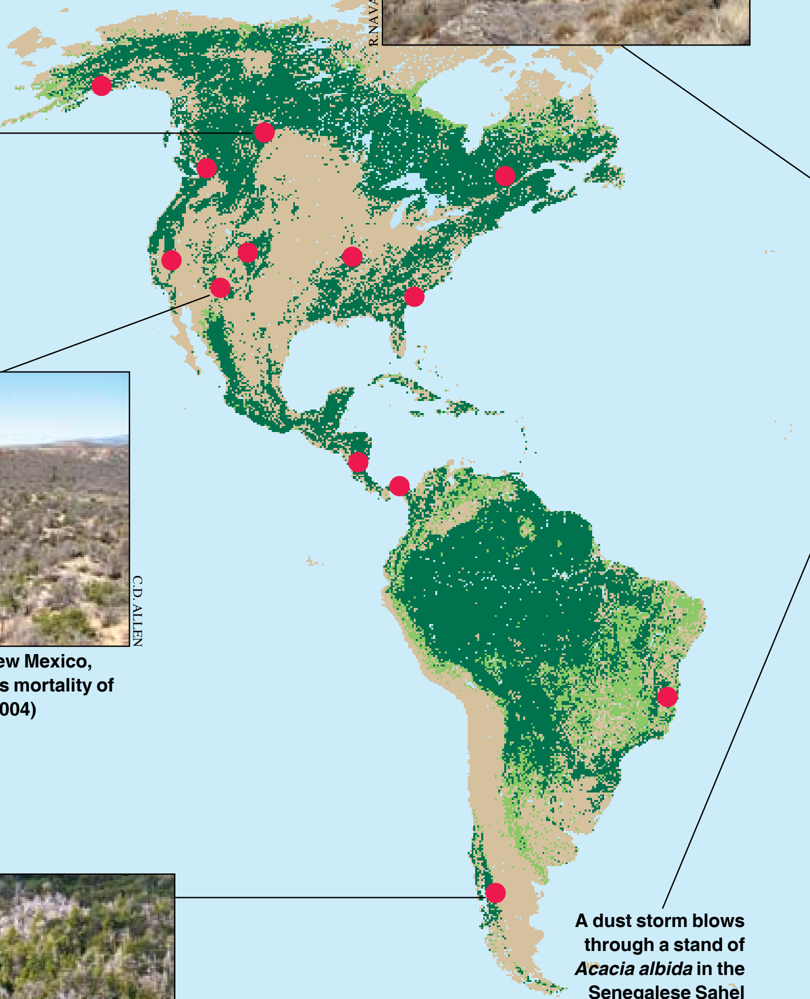
Localities with increased forest mortality related to climatic stress from drought and high temperatures

Drought-induced mortality of *Pinus sylvestris*, Andalucia, Spain (April 2006)

R. NAVARRO

Severe mortality of overstorey aspen (*Populus tremuloides*) following the 2001–2002 drought in the parkland zone of Saskatchewan, Canada (August 2004)

M. MICHAELIAN



C.D. ALLEN

C.D. ALLEN

Mortality after warm drought in the early 2000s, Jemez Mountains, New Mexico, United States: left, *Pinus ponderosa* mortality (July 2006); right, mass mortality of *Pinus edulis* and scattered *Juniperus monosperma* survivors (May 2004)

T. KITZBERGER

Mortality of *Nothofagus dombeyi* in mixed *N. dombeyi–Austrocedrus chilensis* stand, induced by a warm drought in 1998–1999, northern Patagonia, Argentina (September 2004)

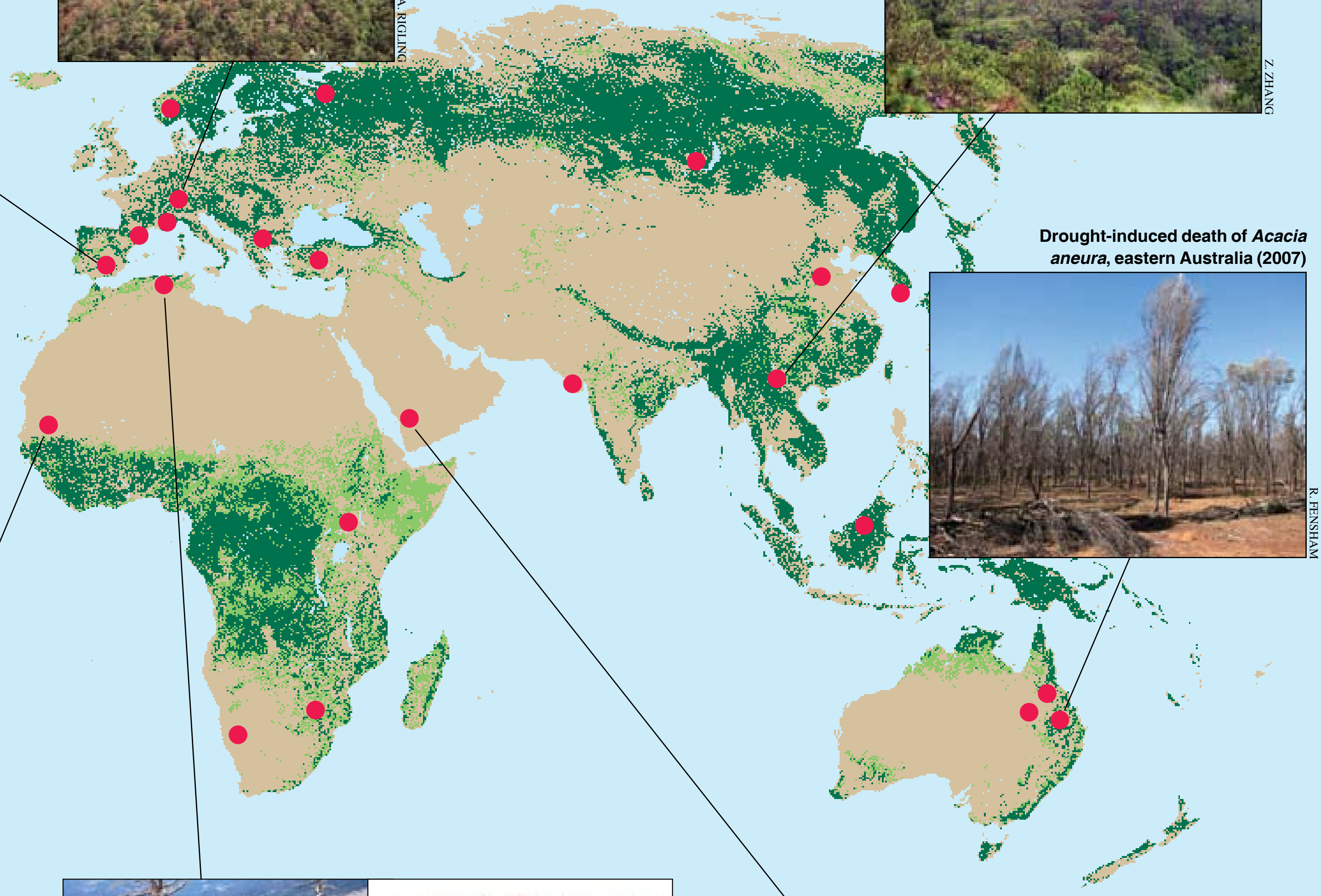
A dust storm blows through a stand of *Acacia albida* in the Senegalese Sahel where dieback was documented in the last half of the twentieth century (1993)

P. GONZALEZ

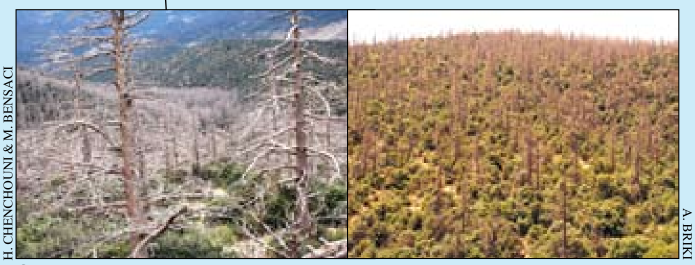
Note: Only localities from the Table are shown; many additional localities are mapped in Allen *et al.*, 2009.

Climate-induced mortality of *Pinus sylvestris*, Valais, Switzerland (1999)

Pinus yunnanensis stand, Yunnan Province, China, showing mortality induced by a drought that resulted in outbreaks of *Tomicus yunnanensis* and *Tomicus minor* shoot beetles from 2003 to 2005 (July 2005)



Drought-induced death of *Acacia aneura*, eastern Australia (2007)



Cedrus atlantica mortality triggered by drought, Belezma National Park, Algeria, with surviving understorey including *Quercus ilex* (2007)

Dieback and decline of *Juniperus procera*, Saudi Arabia (March 2006) and potentially lead to extensive forest dieback.

Third, scientists lack adequate knowledge of the feedback and non-linear interactions between climate-induced forest stress and other climate-related disturbance processes, such as insect outbreaks and fire, that can cause widespread forest mortality (Allen, 2007).

These scientific uncertainties about fundamental tree mortality processes represent a key limitation to more accurate quantitative modelling of future climate-induced forest dieback (e.g. Huntingford *et al.*, 2008). Accordingly they also limit the ability to predict the implications of dieback for the potential of global forests to sequester excess atmospheric carbon or, alternatively, to become carbon sources and thereby contribute to amplified climate change (Lucht *et al.*, 2006).

Overall, additional monitoring of global forest health and new research are needed to improve scientific certainty regarding risks of future climate-induced forest dieback for more accurate input to policy decisions and forest management worldwide. ◆

Bibliography

Allen, C.D. 2007. Cross-scale interactions among forest dieback, fire, and erosion in northern New Mexico landscapes. *Ecosystems*, 10: 797–808.

Allen, C.D., Macalady, A., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Gonzales, P., Hogg, T,. Rigling, A., Breshears, D.D., Fensham, R., Zhang, Z., Kitzberger, T., Lim, J.-H., Castro, J., Running, S.W., Allard, G., Semerci, A. & Cobb, N. 2009. Drought-induced forest mortality: a global overview reveals emerging climate change risks. (Submitted for publication)

Angert, A., Biraud, S., Bonfils, C., Henning, C.C., Buermann, W., Pinzon, J., Tucker, C.J. & Fung. I. 2005. Drier summers cancel out the CO_2 uptake enhancement induced by warmer springs. *Proceedings of the National Academy of Sciences of the United States of America*, 102(31): 10823–10827.

Auclair, A.N.D. 1993. Extreme climatic fluctuations as a cause of forest dieback in the Pacific Rim. *Water, Air and Soil Pollution*, 66(3–4): 207–229.

Barber, V.A., Juday, G.P. & Finney, B.P. 2000. Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. *Nature*, 405: 668–673.

Boisvenue, C. & Running, S.W. 2006. Impacts of climate change on natural forest productivity – evidence since the middle of the 20th century. *Global Change Biology*, 12(5): 862–882.

Breda, N., Huc, R., Granier, A. & Dreyer, E. 2006. Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes and long-term consequences. *Annals of Forest Science*, 63: 625–644.

Breshears, D.D., Cobb, N.S., Rich, P.M., Price, K.P., Allen, C.D., Balice, R.G., Romme, W.H., Kastens, J.H., Floyd, M.L., Belnap, J., Anderson, J.J., Myers, O.B. & Meyer, C.W. 2005. Regional vegetation die-off in response to global-change-type drought. *Proceedings of the National Academy of Sciences of the United States of America*, 102(42): 15144–15148.

Ciais, P., Reichstein, M., Viovy, N., Granier, A., Ogee, J., Allard, V., Aubinet, M., Buchmann, N., Bernhofer, C., Carrara, A., Chevallier, F., De Noblet, N., Friend, A.D., Friedlingstein, P., Grunwald, T., Heinesch, B., Keronen, P., Knohl, A., Krinner, G., Loustau, D., Manca, G., Matteucci, G., Miglietta, F., Ourcival, J.M., Papale, D., Pilegaard, K., Rambal, S., Seufert, G., Soussana, J.F., Sanz, M.J., Schulze, E.D., Vesala, T. & Valentini, R. 2005. Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature,* 437(7058): 529–533.

Ciesla, W.M. & Donaubauer, M.E. 1994. *Decline and dieback of trees and forests: a global overview*. FAO Forestry Paper No. 120. Rome, FAO.

Clark, D.A. 2004. Sources or sinks? The responses of tropical forests to current and future climate and atmospheric composition. *Philosophical Transcripts of the Royal Society of London, Series B*, 359: 477–491.

Desprez-Loustau, M.-L., Marcais, B., Nageleisen, L.-M., Piou, D. & Vannini, A. 2006. Interactive effects of drought and pathogens in forest trees. *Annals of Forest Science*, 63: 597–612.

FAO. 2006. *Global Forest Resources Assessment 2005 – Progress towards sustainable forest management*. FAO Forestry Paper No. 147. Rome.

Fensham, R.J., Fairfax, R.J. & Ward, D.P. 2009. Drought-induced tree death in savanna. *Global Change Biology*. (In press)

Hicke, J.A., Logan, J.A., Powell, J. & Ojima, D.S. 2006. Changing temperatures influence suitability for modeled mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in the western United States. *Journal of Geophysical Research*, 111: G02019.

Huntingford, C., Fisher, R.A., Mercado, L., Booth, B.B.B., Sitch, S., Harris, P.P., Cox, P.M., Jones, C.D., Betts, R.A., Malhi, Y., Harris, G., Collins, M. & Moorcroft, P. 2008. Towards quantifying uncertainty in predictions of Amazon "die-back". *Philosophical Transcripts of the Royal Society of London, Series B*, 363(1498): 1857–1864.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate change 2007 –the physical science basis.* Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge, UK, Cambridge University Press.

Jump, A., Hunt, J.M. & Peñuelas, J. 2006. Rapid climate change-related growth decline at the southern range edge of *Fagus sylvatica*. *Global Change Biology*, 12: 2163–2174.

Kurz, W.A., Stinson, G., Rampley, G.J., Dymond, C.C. & Neilson, E.T. 2008.

Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. *Proceedings of the National Academy of Sciences of the United States of America*, 105: 1551–1555.

Lewis, S.L. 2005. Tropical forests and the changing earth system. *Philosophical Transcripts of the Royal Society of London, Series B*, 361: 195–210.

Lucht, W., Schaphoff, S., Erbrecht, T., Heyder, U. & Cramer, W. 2006. Terrestrial vegetation redistribution and carbon balance under climate change. *Carbon Balance and Management*, 1: 6.

McDowell, N., Pockman, W.T., Allen, C.D., Breshears, D.D., Cobb, N., Kolb, T., Sperry, J., West, A., Williams, D. & Yepez, E.A. 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? Tansley Review. *New Phytologist*, 178: 719–739.

Nepstad, D.C., Stickler, C.M., Soares-Filho, B. & Merry, F. 2008. Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point. *Philosophical Transcripts of the Royal Society of London, Series B*, 363(1498): 1737–1746.

Nepstad, D.C., Tohver, I.M., Ray, D., Moutinho, P. & Cardinot, G. 2007. Mortality of large trees and lianas following experimental drought in an Amazon forest. *Ecology*, 88(9): 2259–2269.

Peñuelas, J., Lloret, F. & Montoya, R. 2001. Severe drought effects on Mediterranean woody flora in Spain. *Forest Science*, 47: 214–218.

Raffa, K.F., Aukema, B.H., Bentz, B.J., Carroll, A.L., Hicke, J.A., Turner, M.G. & Romme, W.H. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. *Bioscience*, 58(6): 501–517.

Seager, R., Ting, M., Held, I., Kushnir, Y., Lu, J., Vecchi, G., Huang, H.-P., Harnik, N., Leetmaa, A., Lau, N.-C., Li, C., Velez, J. & Naik, N. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, 316: 1181–1184.

Soja, A.J., Tchebakova, N.M., French, N.H.F., Flannigan, M.D., Shugart, H.H., Stocks, B.J., Sukhinin, A.I., Varfenova, E.I., Chapin F.S. & Stackhouse, P.W. Jr. 2007. Climate-induced boreal forest change: Predictions versus current observations. *Global and Planetary Change*, 56(3-4): 274–296.

Swetnam, T.W. & Betancourt, J.L. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. *Journal of Climate*, 11: 3128–3147.

van Mantgem, P.J., Stephenson, N.L., Byrne, J.C., Daniels, L.D., Franklin, J.F., Fulé, P.Z., Harmon, M.E., Larson, A.J., Smith, J.M., Taylor, A.H. & Veblen, T.T. 2009. Widespread increase of tree mortality rates in the western United States. *Science*, 323: 521–524. ◆

Tree improvement programmes for forest health – can they keep pace with climate changes?

A. Yanchuk and G. Allard

Can tree improvement programmes develop "generic" resistance to offset potential new pest and disease problems that may arise more rapidly with climate change?

As forest geneticists consider physiological adaptations of forest tree populations under various climate change scenarios, they must also take into account likely impacts from new insect pest and disease introductions, as well as increased natural disturbances from native pests. What lessons can be learned from past investments in disease and pest resistance research and genetic improvement, particularly with the challenges of climate change scenarios? Can more generic and general resistance be developed to offset potential new pest and disease problems that will arise within a time frame of less than a decade?

The world's main commercial tree improvement programmes have focused primarily on productivity improvements in the first few generations of breeding, but they have sometimes included an insect pest and disease resistance component. Many pest and disease resistant individuals, and even specific resistance genes, have been found in forest tree species, and some are currently employed in breeding.

This article summarizes the results of a recent worldwide survey of research on insect and disease resistance which suggests that although some targeted resistance programmes have had substantial impacts on improving the health of planted forests, most of the gains have been for only a small number of major commercial species and have taken decades to develop. The article suggests that past approaches may not serve well under rapid climate change, and also identifies five future challenges that could undercut the potential for tree

As warming climate is thought to trigger outbreaks of Dothistroma needle cast disease (shown in lodgepole pine,* Pinus contorta*), resistance mechanisms that may reduce infection to several species of needle cast fungi would be worth pursuing

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Partial list of major breeding programmes in the world developing and planting insect pest and disease resistant forest trees

Tree species	Insect pest or disease problem	Type	Country
Pinus monticola	*Cronartium ribicola*	Fungus	United States
Pinus taeda	Fusiform rust disease (*Cronartium quercuum*)	Fungus	United States
Populus spp.	*Melampsora* spp.; *Venturia populina; Septoria populicola*	Disease, insects	United States
		Insects	China
		Disease, insects	Europe
Salix spp.	Leaf rust	Disease	Sweden
		Disease, insects	United States
Pinus radiata	Dothistroma needle blight (*Mycosphaerella pini*)	Fungus	New Zealand
Picea sitchensis	Green spruce aphid (*Elatobium abietinum*)	Insect	Denmark
Picea glauca and *P. sitchensis*	White pine weevil (*Pissodes strobi*)	Insect	Canada

improvement programmes to improve forest health in changing climates.

INFLUENCE OF CLIMATE CHANGE ON PEST AND DISEASE PROBLEMS

Climate change is expected to result in or require large-scale movement of species, and populations within species, into climatic zones where they may not currently exist. Bold new forest management strategies will be needed to offset adaptational lags of species and their populations to maintain productivity and forest health. Tree vigour and productivity will be the first line of defence against insect pests and diseases.

Furthermore, ranges of insect pests are expected to expand under several climate change modelling scenarios (e.g. nun moth, *Lymantria monacha*; gypsy moth, *Lymantria dispar*) (Vanhanen *et al.*, 2007). Diseases and insect pests continue to be introduced and to invade or threaten regions outside their natural distribution ranges (Lovett *et al.*, 2006). Warming climate is thought to be a major cause of epidemic outbreaks of native diseases and pests that are causing relatively new and catastrophic problems; recent examples include Dothistroma needle cast disease (Woods, Coates and Hamann, 2005) and mountain pine beetle (Aukema *et al.*, 2008) in western Canada.

RESULTS OF RESISTANCE BREEDING PROGRAMMES TO DATE

A survey of the literature to evaluate the effectiveness of tree breeding research for disease and pest resistance, carried out by FAO with assistance from the British Columbia Forest Service, Canada, classified activities according to four levels of breeding programme development:

- Status 1 – large breeding programmes that have resulted in operational planting of resistant material (seed-orchard seed or other propagule types);
- Status 2 – large research or breeding programmes that have not yet resulted in operational planting;
- Status 3 – large research or breeding programmes that have identified genetic variation in resistance in genetic/provenance trials;
- Status 4 – studies that have identified genetic variation in resistance in small research seedling or clonal trials.

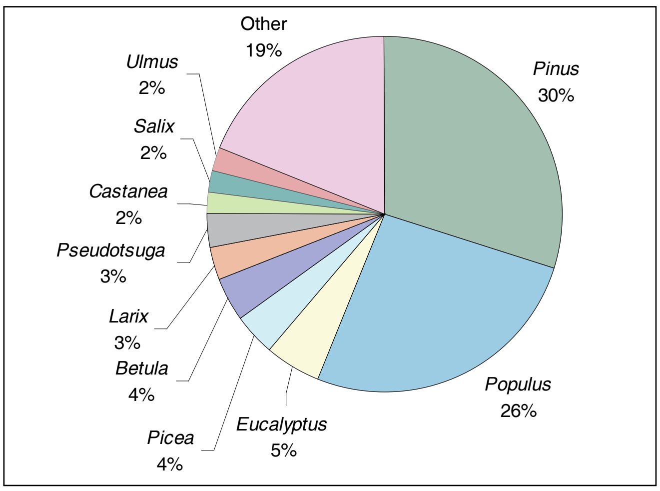
Although the technical approaches that can be applied are somewhat predetermined by these levels, three technologies were also identified to categorize the initiatives further:

- traditional plant breeding methods;
- molecular biology approaches;
- genetic engineering.

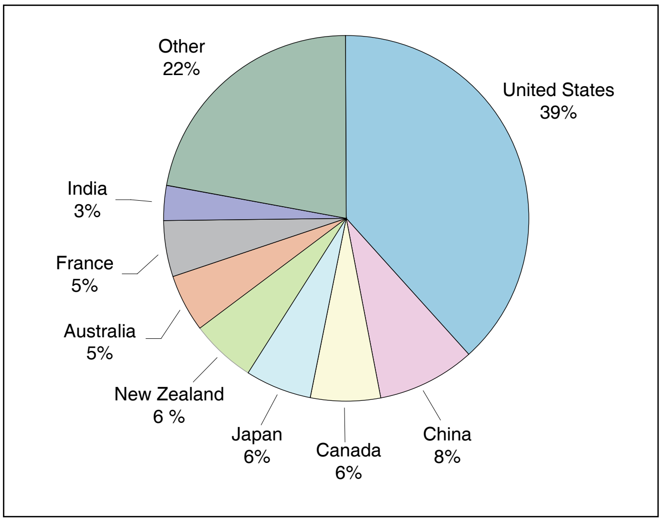
A total of 260 activities on breeding for pest and disease resistance in forest trees were recorded in the review (FAO, 2008). The list was not intended to capture all publications on resistance in a particular species, as some resistance programmes (e.g. that for fusiform resistance in *Pinus taeda*) have been reported in hundreds of scientific papers. The intention was rather to represent a sample of the literature in each programme area. The Table summarizes some of the programmes that have had the largest impact to date.

Survey summary

By forest tree species. Thirty-six tree genera were represented. Pines (*Pinus* spp.) and poplars (*Populus* spp.) were the two most commonly investigated genera, together representing more than half of the activities recorded (Figure 1).



1
Insect pest and disease resistance breeding programmes, by tree genus



2
Insect pest and disease resistance breeding programmes, by country

The most studied tree species included *Pinus radiata* (16 records), *P. taeda* (nine records), and *P. monticola* and *P. ponderosa* var. *ponderosa* (six records each). Other species with at least four activities were *Picea abies*, *Pinus contorta*, *Betula pendula*, *Cryptomeria japonica*, *Eucalyptus globulus*, *Hevea brasiliensis*, *Pinus lambertiana* and *Populus deltoides*.

By pest type and species. About 54 percent of reported activities investigated tree resistance to disease species, 36 percent targeted forest insect pests and 6 percent investigated both pest types. Resistance to mammals was the focus of only six activities (about 2 percent), and one activity dealt with nematode resistance.

The most commonly targeted insect pest species included *Chrysomela scripta* (five activities) and *Pissodes strobi* and *Thecodiplosis japonensis* (four activities each). The most commonly targeted disease species included *Cronartium ribicola* (18 activities) and *Cronartium quercuum* (seven activities). Four activities each addressed *Diplodia pinea*, *Heterobasidion annosum*, *Melampsora larici-populina* and *Ophiostoma ulmi*.

By country. The majority of research activities are published in developed countries, led by the United States with almost 39 percent of all activities (Figure 2), although some emerging developing countries such as China (about 8 percent), India (3 percent) and Brazil (1 percent) are active or have at least published and disseminated some results.

By approach. About 68 percent of the research focused on traditional plant breeding methods. Genetic engineering was the focus of almost 15 percent of the activities and molecular biology almost 13 percent. About 5 percent used a combination of the three approaches.

By status of breeding programme. About 63 percent of all research activities are Status 4, 22 percent are Status 3 and only 6 percent are Status 2. Just 9 percent of the recorded activities are Status 1, i.e. at the stage of planting resistant material operationally; furthermore many of these activities, although carried out by different organizations, represent work with the same tree species and pest or disease problem.

Impact of resistance work in planted forests

In general, the survey clearly shows that despite a large body of published research over more than 50 years, from hundreds of research initiatives or programmes around the world, relatively few programmes have developed resist-

A relatively successful disease resistance programme targets white pine blister rust (*Cronartium ribicola*) in North America; a complex bark reaction kills tissue around the infection in a* Pinus strobus *tree with tolerance to the disease

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Isolation bags on western red cedar (*Thuja plicata*) for controlled pollination for deer browse resistance studies

ant material for operational planting. Practical impacts from resistance breeding programmes have only been documented for four to five major commercial pest and disease problems.

For disease resistance, the two most successful programmes appear to be the fusiform rust resistance improvement in *Pinus taeda* and *Pinus elliottii* in the southern United States, and the white pine blister rust resistance programmes in the Inland Empire region of southern California and the Pacific Northwest of North America. *Pinus lambertiana* resistance to blister rust in California and southern Oregon, United States, is also notable. The most impressive documentation of success has been for fusiform resistance; average worth of plantations established with fusiform-resistant *P. taeda* improved 6 to 40 percent over plantations established with susceptible stock, while improvements for *P. elliottii* ranged from 40 to 90 percent (Brawner *et al.*, 1999).

Gains from the first-generation programmes of non-major gene resistant stock in *Pinus strobus* range from 3 to 70 percent survival (with one rare example of major gene resistance in *Pinus lambertiana* and *P. monticola* inferring 100 percent survival in the simplest situation [Kinloch *et al.*, 1999]). These figures may be underestimates as the survival of more recently planted material may be higher; nevertheless, the results clearly show that genetic gains are possible and important.

Several programmes (e.g. chestnut resistance to blight) seem to be on the verge of having novel materials ready for use; however, a long time will be required before their ecological or economic impacts can be evaluated. Dothistroma-resistant breeds in *Pinus radiata* have been developed, but the problem has largely been addressed through silvicultural practices (Mead, 2005).

In comparison with disease resistance, pest resistance programmes are less well developed and have resulted in less material that has reached large-scale reforestation programmes, although there is substantial work in the area (as shown in the Table). The survey revealed only two programmes using traditional plant breeding methods that could be classified as Status 1, one for spruce aphid (*Elatobium abietinum*) resistance (Harding, Rouland and Wellendorf, 2003) in Europe and the other for spruce terminal weevil (*Pissodes strobi*) resistance in British Columbia, Canada (King *et al.*, 1997). Work on transgenic material for resistance to stem-boring and leaf-eating insects is increasing; operational planting of this material is in its infancy but has been reported with poplars in China (Ewald, Hu and Yang, 2006). Work on *Eucalyptus* resistance to a number of leaf insects is increasing, but to the authors' knowledge the resistance has not been incorporated in materials being planted commercially.

Considerable time and resources have been invested to obtain resistant genotypes, gain experience in their use and achieve impacts in improving plantation health. Initiating an improvement programme for a tree species, even for a few simple traits, requires substantially more years than for a crop species. With a long process involving selection of germplasm for field testing, rearing of test stock, test establishment and meas-

Spruce terminal weevil (*Pissodes strobi*) larvae migrate down the leader to girdle and kill the top of the tree; a breeding programme for this pest in western Canada is one of the few insect resistance programmes that has reached the operational planting stage

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A few surviving lodgepole pine trees resistant to mountain pine beetle in a young (age 20 years) family trial; high levels of attack in such long-term research field installations are typically an important first "genetic screening" for resistance to bark-chewing insects

urements at appropriate ages, selection of best material and establishment in seed or hedge orchards, it is not surprising that the successful programmes have taken one, two or even more decades to identify and develop silviculturally useful genetic resistance.

CHALLENGES FOR EFFECTIVE RESULTS IN CHANGING CLIMATES

Difficulty of finding specific mechanisms that explain plant or tree resistance

While many insect pest and disease resistance traits can be scored relatively easily by observing the presence or absence of the pest or disease on an individual tree, detailed phenotypic assessments of host reaction or pest behaviour (e.g. landing on and then leaving a tree) are required to develop a better understanding of what general mechanisms of resistance are at work.

Decades of research on herbivory in *Betula pubescens* (e.g. Haukioja, 2003) have uncovered a wide range of variations in birch that can impart resistance. For instance, there is a large spectrum of leaf compounds that change over the growing season; the level of resistance varies by herbivore species; and simple changes in nutrients, water content and leaf toughness were found to be as important as any of the more complex and detailed anatomical or chemical profiles in birch genotypes (Riipi *et al.*, 2005). To identify mechanisms of resistance that may impart some general resistances to classes of insect pests and diseases, and to incorporate this knowledge into programmes that can potentially deliver resistant germplasm, will be difficult but extremely valuable. Development of general resistance becomes more critical if it is not possible to predict what future insect pest species or pathogens will be encountered with climate change.

Transferability of research on wild trees to pedigreed trees in genetic improvement programmes

Studies carried out on trees in natural settings will not necessarily assist breeding programmes in developing more resistant germplasm. Much research on insect pest or disease interaction with host trees in the wild is important for modelling purposes (e.g. on spread rates and impacts in wild forests) and is of evolutionary interest, but it may not be possible to extrapolate the results to species or populations that have been artificially migrated under climate change adaptation strategies (Millar, Stephenson and Stephens, 2007). Work with pedigreed material from breeding programmes, if available and adequately challenged by various pests or diseases, may also be able to provide the basic information needed for stand or landscape impact models.

Decreasing resources for traditional genetic improvement of forest trees

In spite of the impressive progress to date in some programmes, it is likely that fewer resources will be available in the future for the study of specific host-pest interactions in classical tree improvement programmes. Globally, traditional training in quantitative genetics – a necessary skill set in tree breeding – has been waning (Eisen, 2008; Knight, 2003; Morris, Edmeades and Pehu, 2006). In addition, many of the largest and most successful tree breeding programmes are currently struggling because of major financial and structural changes in the forest industry (Byram, Miller and Raley, 2006). Available research resources will need to focus on testing for, developing and using resistances that may be able to help thwart both current and new, unknown challenges. Cross-resistance, i.e. resistance against many classes of pests or diseases (e.g. Andrew *et al.*, 2007), if it can be identified and tested adequately, may have the most utility in the future.

Lodgepole pine provenance test at age 30 years; field tests such as these have been important for studying the effects of climate change on adaptive genetic variation in growth potential and pest and disease resistance among forest tree populations


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Populus trichocarpa ***cuttings being lifted in the nursery for research plantings in field trials; poplars are widely used in genomics and transgenics, but long-term basic field studies are still needed to study natural levels of resistance and adaptation to climate change***

Adjusting investments in molecular biology and genomics research

The enormous sums invested in molecular biology in many countries, while being of great scientific interest, must be better aligned with applied programmes. The survey noted that approximately 13 percent of initiatives used molecular biology approaches. Genomics information is evolving at a rapid pace, and many products or tools will likely be of substantial interest to breeders. For instance, it may become possible to narrow down the key elements (e.g. families of genes) operative in resistance, such as a compound from resin terpenoid biosynthesis and production, alkaloid expressions, traumatic resin production, formation of resin ducts or physical barriers such as bark thickness or stone cells. However, the largest challenge will be in making the proper linkages between markers, gene expression measures and the phenotypic expressions of the trait in large pedigreed forest tree populations, and then determining how tree responses or traits affect pest or pathogen response.

Role of transgenic trees

Transgenic technology can address some specific pest problems temporarily, but it still must be considered only one tool within well-developed breeding programmes. Because trees are planted across landscapes, and now because of the added complexities that climate change will impose, adequate field testing over space and time will be needed to ensure that gene expression is stable within different genotypes. However, for short-rotation species such as poplar, it may be possible to manage transgenic trees using approaches similar to those currently being used in agricultural crops.

SUMMARY AND CONCLUSIONS

The results of the survey highlight three issues. First, since the "reaction time" for developing genetic options for insect pest and disease resistance has typically been in the order of decades, will this approach be useful in a world with rapidly changing climates? In the authors' opinion, probably not. Therefore it may be necessary to develop strategies that may provide some "pre-emptive" or general resistances.

Second, since there may be little or no lead time to know which pests or diseases will pose threats in the future, are there some better "generic" forms or classes of resistance that could be developed in advance against various classes of insects or diseases? It would be highly desirable, if possible, to identify mechanisms of resistance that may be more affordable and allow for a shorter turnaround and development time than at present.

Third, will the resistance mechanisms currently being used be able to provide some protection from new or related pests and diseases?

Although a more general type of cross-resistance should not be expected to be a typical feature of most resistance mechanisms (Panda and Khush, 1995; Riipi *et al.*, 2005), it may now be important to seek to understand the degree of variation present in currently selected elite parent trees making up the seed production and breeding populations. A reduction in the number of genotypes that researchers should and can afford to work with needs to be tempered with the difficulty of accommodating more traits (Verryn, 2008), particularly if negative genetic correlations are present between traits of interest. Moreover, resistance does not always incur a physiological cost (e.g. King *et al.*, 1997), so mechanisms of resistance that are positively correlated with growth would also be desirable ones to pursue.

In summary, after five decades of research on insect pest and disease resistance in trees, resistance breeding has had significant local impacts; however, the successes are largely for a few of the main commercial programmes which have had substantial resources and structures in place to deliver the gain.

In the future, funding agencies and researchers may need to focus declining resources and research capacity on species for which silvicultural options to mitigate losses to insect pests and diseases are few. Research should also be focused on genotypes that are already in tree improvement programmes or that could form the basis of a programme.

Better alignment of forest genetics and forest health research programmes will be required if traditional tree improvement programmes are to capitalize on past investments in insect pest and disease resistance research and help mitigate the projected negative impacts of climate change on forest productivity and health. This is likely to become imperative with projections of increased pest and disease risks in the future. ◆

Bibliography

Andrew, R., Wallis, I., Harwood, C., Henson, M. & Foley, W. 2007. Heritable variation in the foliar secondary metabolite sideroxylonal in *Eucalyptus* confers cross-resistance to herbivores. *Oecologia*, 153(4): 891–901.

Aukema, B.H., Carroll, A.L., Zheng, Y., Zhu, J., Raffa, K.F., Moore, D., Stahl, K. & Taylor, S.W. 2008. Movement and outbreak populations of mountain pine beetle: influences of spatiotemporal patterns and climate. *Ecography*, 31: 348–358.

Brawner, J.T., Carter, D.R., Huber, D.A. & White, T.L. 1999. Projected gains in rotation-age volume and value from fusiform rust resistant slash and loblolly pines. *Canadian Journal of Forest Research*, 29: 737–742.

Byram, T.D., Miller, L.G. & Raley, E.M. 2006. *Fifty-fourth progress report of the cooperative forest tree improvement program*. College Station, Texas, USA, Texas Forest Service, Texas A&M University.

Eisen, E.J. 2008. Can we rescue an endangered species? *Journal of Animal Breeding and Genetics*, 125: 1–2.

Ewald, D., Hu, J. & Yang, M. 2006. Transgenic forest trees in China. *In* M. Fladung & D. Ewald, eds. *Tree transgenics: recent developments*, pp. 25-45. Berlin & Heidelberg, Germany, Springer-Verlag.

FAO. 2008. *Selection and breeding for insect and disease resistance*. Internet document. Available at: www.fao.org/forestry/26445

Harding, S., Rouland, H. & Wellendorf, H. 2003. Consistency of resistance by the spruce green aphid in different ontogenetic stages of Sitka spruce. *Agricultural and Forest Entomology*, 5(2): 107.

Haukioja, E. 2003. Putting the insect into the birch–insect interaction. *Oecologia*, 136: 161–168.

King, J.N., Yanchuk, A.D., Kiss, G.K. & Alfaro, R.I. 1997. Genetic and phenotypic relationships between weevil (*Pissodes strobi*) resistance and height growth in spruce populations of British Columbia. *Canadian Journal of Forest Research*, 27: 732–739.

Kinloch, B.B., Sniezko, R.A., Barnes, G.D. & Greathouse, T.E. 1999. A major gene for resistance to white pine blister rust in western white pine from the western Cascade Range. *Phytopathology*, 89: 861–867.

Knight, J. 2003. Crop improvement: a dying breed. *Nature*, 421: 568–570.

Lovett, G.M., Canham, C.D., Arthur, M.A., Weathers, K.C. & Fitzhugh, R.D. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. *Bioscience*, 56: 395–405.

Mead, D.J. 2005. Opportunities for improving plantation productivity – how much? how quickly? how realistic? *Biomass and Bioenergy*, 28: 249–266.

Millar, C.I., Stephenson, N.L. & Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications*, 17: 2145–2151.

Morris, M., Edmeades, G. & Pehu, E. 2006. The need for plant breeding capacity: what roles for the public and private sectors. *HortScience*, 41: 30–39.

Panda, N. & Khush, G.S. 1995. *Host plant resistance to insects*. Wallingford, UK, CAB International.

Riipi, M., Kause, A., Haukioja, E., Ossipov, V., Ossopova, S. & Pihlaja, K. 2005. Variable responses of folivorous sawflies to leaf quality of mountain birch. *Canadian Journal of Forest Research*, 35: 189–198.

Vanhanen, H., Veteli, T.O., Pailvinen, S., Kellomaki, S. & Niemala, P. 2007. Climate change and range shifts in two insect defoliators: gypsy moth and nun moth – a model study. *Silva Fennica*, 41: 621–638.

Verryn, S.D. 2008. Breeding for wood quality – a perspective for the future. *New Zealand Journal of Forestry Science*, 38: 5–13.

Woods, A., Coates, K.D. & Hamann, A. 2005. Is an unprecedented Dothistroma needle blight epidemic related to climate? *Bioscience*, 55: 761–769. ◆

Adapting to climate change in United States national forests

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A review of climate change adaptation options in the United States offers practical information for resource managers to help them adapt their forest management goals and practices to expected climate change impacts.

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Climate change is already affecting forests and other ecosystems, and additional, potentially more severe impacts are expected (IPCC, 2007; CCSP, 2008a, 2008b). As a result, forest managers are seeking practical guidance on how to adapt their current practices and, if necessary, their goals. Adaptations of forest ecosystems, which in this context refer to adjustments in management (as opposed to "natural" adaptation), ideally would reduce the negative impacts of climate change and help managers take advantage of any positive impacts.

This article summarizes key points from a review of climate change adaptation options for United States national forests (Joyce *et al.*, 2008) produced under the auspices of the United States Climate Change Science Program (CCSP) (see Box). The study sought to provide practical information on potential adaptation options for resource managers by asking:

- How will climate change affect the ability of resource managers to achieve their management goals?
- What might a resource manager do to prepare the management system for climate change impacts while maintaining current goals (and constantly evaluating if these goals need to be modified or re-prioritized)?

The Climate Change Science Program and adaptation options for national forests

The United States Climate Change Science Program (CCSP) (see www.climatescience.gov) aims to build a better understanding of how the earth's climate is changing, of humanity's role in these changes, and of how societies can mitigate and adapt to their impacts. The programme has five strategic goals:

- **to improve knowledge of past and present climate;**
- **to improve quantification of the forces bringing about climate changes;**
- **to reduce uncertainty in climate projections;**
- **to understand the sensitivity and adaptability of human systems as well as natural and managed ecosystems;**
- **to explore the uses and limits of knowledge to manage risks and opportunities related to climate change.**

To achieve these goals, CCSP commissioned 21 synthesis and assessment products (SAPs). Of these, SAP 4.4, led by the United States Environmental Protection Agency (USEPA), reviewed possible management adaptations for climate-sensitive ecosystems and resources. Recognizing that successful adaptation will be context dependent, SAP 4.4 explored options for a range of federally managed lands and waters: national parks, national forests, fish and wildlife refuges, wild and scenic rivers, marine protected areas and coastal estuaries.

EXPECTED CLIMATE CHANGE IMPACTS ON UNITED STATES FOREST MANAGEMENT GOALS

Climate change will directly affect the ecosystem services provided by national forests and will exacerbate the impacts of current natural and anthropogenic stress factors. Wildfires, non-native and native invasive species and extreme weather events are the most critical stress factors that climate change will amplify within national forests. Reduced snowpack, earlier snowmelt and altered hydrology associated with warmer temperatures and changing precipitation patterns will complicate water management, particularly in the western states, and will affect other ecosystem services that national forests provide (e.g. winter recreational opportunities). Drought may become more difficult to manage across the United States. While elevated atmospheric carbon dioxide and warming temperatures may enhance near-term forest

Impacts of climate change on the forest management goals of the United States Forest Service

Goal	Desired or intended outcome	Possible climate change impacts	Adaptation options
Restore, sustain, and enhance national forests	Maintain forest health, productivity, diversity and resistance to severe disturbances	Longer, warmer growing seasons Altered fire regimes Shifts in seasonality of hydrological processes Intense droughts	Reduce fuel loads in forests Increase use of wildland fire use Enhance the early detection and response strategy associated with non-native invasive species
Provide and sustain benefits to the country's people	Maintain multiple socio-economic benefits to meet society's needs over the long term, including a reliable supply of forest products, energy resource needs and market-based conservation	Climate change interacting with current stress factors such as insect pests and disease, wildfire, legacy of past management and air pollution Shifts in forest species composition Increased erosion events impairing watershed condition	Increase efforts to reduce current stress factors Incorporate long-term climate change into wildland fire planning Develop silvicultural treatments to reduce drought stress Review genetic guidelines for reforestation
Conserve open space	Maintain the environmental, social and economic benefits of forests, protecting these resources from conversion to other uses, and helping private landowners and communities manage their land as sustainable forests	Large-scale forest dieback or vegetation type conversions as a result of more frequent extreme events Altered landscape and successional dynamics Increasing fragmentation of forest ecosystems and wildlife habitat	Provide technical assistance to urban foresters to sustain urban trees Develop corridors for species migration and habitat protection
Sustain and enhance outdoor recreation opportunities	Maintain high-quality outdoor recreation opportunities in national forests available to the public	Increased air and stream temperatures Reduced snowpack Altered in-stream flows	Evaluate recreational impact on ecosystems under a changing climate Expand recreational opportunities across all four seasons Redesign roads and trails to withstand increased rainfall intensity
Maintain basic management capabilities of the Forest Service	Develop administrative facilities, information systems, and landownership management strategies to support wide-ranging natural resource challenges	Poor accessibility or lack of current information on climate change projections, ecosystem impacts and socio-economic impacts on local communities Uncertainty associated with that information	Increase technical understanding by developing educational material for employees and stakeholders Incorporate climate change into planning processes Enhance research partnerships
Engage urban citizens	Provide broader access to long-term environmental, social, economic and other benefits provided by the Forest Service	Exacerbation of the stress that urban environments place on ecosystems, as a result of warming temperatures Increased wildfire and drought risks in surrounding landscapes, which may compromise ability to maintain water quality and availability	Expand conservation education programmes to include climate change Seek opportunities to educate national forest visitors on climate change
Provide science-based applications and tools for sustainable natural resource management	Ensure that the best available science-based knowledge and tools inform Forest Service management decisions	Need for management tools that incorporate climate change considerations Need to revise current management practices that are based on assumptions about ecosystems and climate that may be invalid in the future	Establish stronger relationships between scientific researchers and management to help identify resilience thresholds for key species and ecosystem processes, determine which thresholds will be exceeded, prioritize projects with a high probability of success and identify species and vegetation structures tolerant of increased disturbance

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Subalpine forest mortality in the Sierra Nevada of California – one of the "surprises" of climate change that must now be anticipated (whitebark pine,* Pinus albicaulis*)

productivity where water and nitrogen are not limiting factors, ozone and other industrial pollutants in combination with increasing climate stress are likely to decrease tree growth and severely affect watershed condition.

To fulfil its objectives of sustaining ecosystem health, diversity and productivity to meet the needs of present and future generations, the United States Forest Service has identified seven strategic goals for 2007–2012. Climate change impacts will make the achievement of all seven goals more challenging (Table). In addition, all of the goals have some relation to the current or desired ecosystem condition, which may be difficult or impossible to maintain under the future climate regime. How sensitive each goal is to climate change will depend on several factors including the temporal and spatial nature of climate change, its specific impacts on particular national forest ecosystems, the effects of human activities on these ecosystems and the extent to which current forest management approaches are based on outdated assumptions about climate.

ADAPTATION OPTIONS

Both reactive and proactive approaches may be adopted to cope with the impacts of climate change in national forests. A reactive approach might be justified if uncertainty or costs are considered very high relative to the expected impacts and risks; or if significant cost savings and benefits would result if interventions are implemented only after a climate-related disturbance takes place (e.g. replanting an area with more fire- or drought-resistant tree species after a wildfire or drought-induced insect outbreak).

In many cases, however, proactive approaches – incorporating adaptation options into management and planning processes now, before climate-related events induce major ecosystem changes – may be less expensive and more effective for achieving current forest management goals. Key elements of a proactive approach to adaptation to climate change include:

- reviewing or identifying – and where necessary modifying – forest management goals;
- evaluating the challenges that climate change poses to achieving those goals and to implementing activities planned for that purpose;
- monitoring ecosystems and forest management responses to provide information on which to base the evaluation of vulnerability and risk;
- incorporating uncertainty about the precise impacts of climate change into forest management approaches;
- developing a portfolio or toolbox of forest management strategies.

This type of approach requires enhanced institutional and stakeholder coordination and inputs, especially because of the patchy ownership patterns in and near United States national forests (Figure), the high level of landscape fragmentation and the fact that one-quarter of all national forest lands are legally assigned other land use designations focused more narrowly on wilderness management or

Patchy ("checkerboard") landownership patterns in and near United States national forests emphasize the need to enhance stakeholder coordination in proactive approaches to climate change adaptation, for example to ensure continuous landscape for species to migrate

UNITED STATES FOREST SERVICE

Reduced snowpack associated with warmer temperatures and changing precipitation patterns will complicate water management; conditions typical of late July or early August are seen in early June 2007 (an extremely dry year) in the upper Tuolumne drainage basin in California, the source of San Francisco's municipal water

wild and scenic river management. Further proactive approaches will need to be appraised continually as the climate continues to change and ecological systems respond; such continual changes may also necessitate a modification of the forest management goals.

A portfolio of forest management strategies is needed so that the right tool can be applied to the specific management context. A single approach to adaptation will not work across the diversity of ecosystems within the national forests. The portfolio should include both short- and long-term adaptation options, many of which are modifications of management practices and tools already used by the Forest Service.

Short-term adaptations: building resistance and resilience to climate change

Short-term adaptations are intended to build resistance and resilience so that ecosystems and natural resources are better able to withstand climate change. Increasing resistance may be the only or best option for high-value resources such as forest plantations that are near the end of their rotation or rare resources such as habitat for sensitive species (i.e. species for which population viability is a concern) in areas where future management decisions have not yet been made (Millar, Stephenson and Stephens, 2007). Practices for improving the resistance of high-value resources entail limiting their exposure to climate change impacts such as drought, fire and insects. For example, landscape-scale thinning and fuel reduction treatments can be used to reduce the risk of anomalous crown fire, drought susceptibility and insect outbreaks. Strategically placed firebreaks and other area treatments that reduce the continuity of forest floor debris will be especially important near residential areas, municipal watersheds and habitats that are designated as critical for the survival and recovery of threatened or endangered species.

Resilient ecosystems not only can accommodate gradual changes, but also return to their prior condition after disturbance (Holling, 1973, 2001). In addition to the adaptations to build resistance, resilience-enhancing adaptations emphasize management of regeneration processes. Resilience-enhancing adaptations include efforts to boost population sizes, increase the number (or diversity) of locations where individual populations, species and habitats are managed, and restore key ecosystem conditions and processes following disturbance.

Reducing current sources of stress (e.g. pollution, non-native invasive species, habitat fragmentation and the impacts of current and past extractive activities) is perhaps the most important and effective option for building ecosystem resilience. Increased effort and coordination among land management agencies and private landowners to reduce current stress factors would benefit ecosystems now and potentially reduce future impacts from climate change. An early response and rapid detection system for invasive species, for example, helps the Forest Service respond quickly when the problem is small. Such an approach might be applied to other climate change induced disturbances that have negative impacts on ecosystems, such as more intense floods and windstorms which accelerate erosion.

Another immediate adaptation option is to review existing forest management plans to identify weaknesses in measures for coping with extreme climate-related events (e.g. drought, fire, floods) as well as for managing water use, recreation and extraction of timber, forage and other natural resources before, during and after these disturbances. Such a review could also shed light on the potential impacts of more intense climate-related events in the future. Forest management plans could then be altered based on anticipated changes in rainfall patterns, fire regimes, phenology (the timing of ecological events such as budburst and the arrival of migratory species) and shifts in ecosystem composition, structure and processes. Insights gained from such a review might help managers develop plans to alter the successional trajec-

D. PETERSON

Landscape-scale thinning and fuel reduction treatments represent a short-term adaptation for improved resistance to fire: a 70 000 ha wildfire in the Okanogan-Wenatchee National Forest in Washington State in 2006 caused 100 percent mortality in a high-density mixed conifer stand (left), whereas a stand that had been thinned and had surface fuels removed by prescribed fire sustained low scorch and minimal overstorey mortality (right)

tory of ecosystems after catastrophic fire or wind events and to aim for a condition more likely to thrive under future climate.

Long-term adaptations: managing for change as resilience thresholds are crossed

Thresholds of resilience for many ecosystems are likely to be exceeded over the longer term (more than 50 years) unless greenhouse gas emissions are sharply and quickly reduced (over less than 20 years) (IPCC, 2007). Thus, longer-term adaptation options are needed that over time will help ecosystems and species to respond to climate change and that will help avoid dramatic and abrupt transitions from one ecosystem condition to another (e.g. forest to shrubland). Ensuring that landscapes are connected to permit species migration and dispersal is considered fundamental in this regard (Halpin, 1997; Holling, 2001; Noss, 2001). Likewise, boosting population sizes, protecting or restoring multiple examples of ecosystems and promoting heterogeneous, multiple-age forest stands will increase biological diversity at multiple levels of organization (from genes to landscapes), and hence the potential for natural adaptation.

Implementation of some adaptations will depend in part on the amount of certainty about the trajectory of climate change. Where there is little certainty, it may make sense to ensure that when new trees are planted, reproductive materials include ample genetic diversity. Where confidence in predicted climate changes is higher, managers might actively intervene to assist specific transitions and shifts in species ranges.

Realigning significantly disrupted ecological conditions to current and future climates may be a preferred choice when resilience thresholds are exceeded and restoration to historic pre-disturbance conditions is considered too environmentally challenging, too expensive or not politically feasible. This type of adaptation was implemented for Mono Lake, California; after court-ordered mediation among stakeholders, restoration goals were revised to take into account current climate and future climate uncertainties to determine the most appropriate lake level for present and anticipated future conditions (Millar, Stephenson and Stephens, 2007).

G. FILDES

Longer-term adaptation options are needed that over time will help ecosystems and species to respond to climate change; for example, recent changes in conditions in the Tahoe National Forest in California allow prescribed burning during winter months, a new practice that will help reduce the risk of catastrophic fires

CONCLUSIONS

As climate change continues to affect ecosystem structure, composition and processes, it will be extremely difficult to address every impact. Forest managers will need to focus on achieving realistic outcomes. Establishing a stronger relationship between scientific research and forest management will be helpful in this regard, helping to:

- identify resilience thresholds for key species and ecosystem processes;
- determine which thresholds are likely to be exceeded;
- prioritize projects with a high probability of success;
- identify species and vegetation structures tolerant of increased disturbance.

Adaptation and mitigation options are increasingly being seen as a set of strategies needed to minimize potential negative impacts and to take advantage of possible positive impacts from climate change. Mitigation options may have deleterious ecological consequences on local to regional scales, and adaptation options may elevate greenhouse gas emissions. Thus, it will be important for managers to assess trade-offs and to seek strategies that achieve synergistic benefits between mitigation and adaptation.

Managers will also have to confront what can and cannot be done given limited financial and human resources. No matter what priority setting scheme is selected, it is important to establish criteria for and participation in decision-making through a deliberative, consultative process that ensures that the concerns of all stakeholders are considered. ◆

Bibliography

Climate Change Science Program (CCSP). 2008a. *The effects of climate change on agriculture, land resources, water resources, and biodiversity.* Synthesis and Assessment Product 4.3. Washington, DC, USA, United States Environmental Protection Agency (USEPA).

CCSP. 2008b. *Preliminary review of adaptation options for climate-sensitive ecosystems and resources.* Assessment Product 4.4. Washington, DC, USA, USEPA.

Halpin, P.N. 1997. Global climate change and natural-area protection: management responses and research directions. *Ecological Applications*, 7: 828–843.

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

Holling, C.S. 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, 4: 390–405.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate change 2007: impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge, UK, Cambridge University Press.

Joyce, L.A., Blate, G.M., Littell, J.S., McNulty, S.G., Millar, C.I., Moser, S.C., Neilson, R.P., O'Halloran, K. & Peterson, D.L. 2008. National forests. *In* CCSP, ed. *Preliminary review of adaptation options for climate-sensitive ecosystems and resources*, pp. 3-1 to 3-127. Washington, DC, USA, USEPA.

Millar, C.I., Stephenson, N.L. & Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications*, 17(8): 2145–2151.

Noss, R.F. 2001. Beyond Kyoto: forest management in a time of rapid climate change. *Conservation Biology*, 15(3): 578–590. ◆

The role of forest protected areas in adaptation to climate change

S. Mansourian, A. Belokurov and P.J. Stephenson

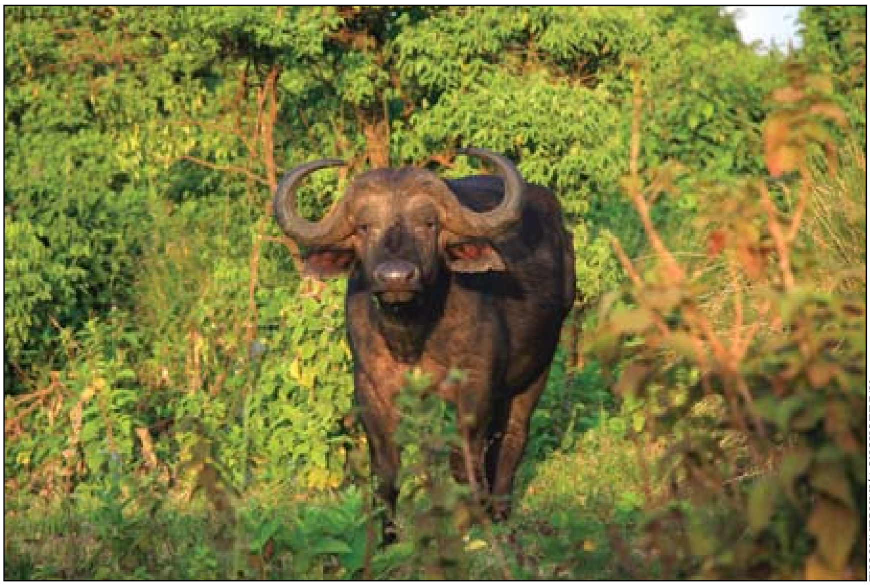
Protected areas are even more important for biodiversity conservation and human livelihoods in a world with a changing climate.

The relationship between forests and climate change is intricate. On the one hand forests can mitigate climate change by absorbing carbon, while on the other they can contribute to climate change if they are degraded or destroyed. In turn climatic changes may lead to forest degradation or loss – which exacerbates climate change further.

A protected area is defined as: "A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2008). Forest protected areas help conserve ecosystems that provide habitat, shelter, food, raw materials, genetic materials, a barrier against disasters, a stable source of resources and many other ecosystem goods and services – and thus can have an important role in helping species, people and countries adapt to climate change. By virtue of their protective status, these forests should remain free from destructive human intervention. They can thus continue to serve as a natural storehouse of goods and services into the future.

Today climate change is one of the main emerging threats facing biodiversity. Up to a quarter of mammal species (about 1 125) (IPCC, 2002) and about 20 percent of bird species (about 1 800) (IPCC, 2007) are at risk of global extinction because of climate change.

Protected areas that were set up to safeguard biodiversity and ecological processes are likely to be affected by climate change in a number of ways. Climate change is expected to cause species to migrate to areas with more favourable temperature and precipitation. There is a high probability that competing, sometimes invasive spe-



In a changing climate, protected areas will take on added importance as safe havens for biodiversity by offering good-quality habitats less vulnerable to climate extremes (African buffalo, Syncerus caffer *– a species susceptible to drought conditions – in Ngorongoro Conservation Area, United Republic of Tanzania)*

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cies, more adapted to a new climate, will move in. Such movements could leave some protected areas with a different habitat and species assemblage than they were initially designed to protect. For example, Scott (2005) found that a stated objective of Prince Albert National Park in Saskatchewan, Canada, to protect ecological integrity "for all time", is unrealistic, as all possible climate scenarios project the eventual loss of boreal forests and their related biodiversity in that area. Climate change is expected to lead to disease outbreaks as pest species may become more resistant or survive longer and new pest species may invade protected areas. For instance, Pounds *et al*. (2006) have traced the much publicized extinction of the Monteverde harlequin frog (*Atelopus* sp.) and the golden toad (*Bufo periglenes*) in the Monteverde forest of Costa Rica nearly two decades ago to warming in the American tropics which is thought to have favoured a particular fungus that infected the amphibians. Climate change is also likely to lead to a higher incidence of fire in some situations and floods in others (IPCC, 2007).

In many cases, the negative effects of climate change on protected areas will be compounded by other stresses, notably those caused by humans, for example through overconsumption, pollution or encroaching urbanization. Biodiversity in protected areas that may already be vulnerable because of these human threats may be more quickly or more severely affected by climate change.

With these and other likely changes, the management of existing protected areas will need to be modified if they are to fulfil their biodiversity conservation role as well as support adaptation to climate change.

This article explores the importance of forest protected areas for ecological, social and economic purposes, drawing on examples from the work carried out around the globe by the World Wide Fund for Nature (WWF) in the context of climate change. It focuses on the broader spatial context and the landscapes within which protected areas are found. It then proposes a range of management and policy responses to ensure that forest protected areas can continue to support biodiversity conservation in the face of climate change.

IMPORTANCE OF FOREST PROTECTED AREAS IN THE FACE OF CLIMATE CHANGE

Protected areas have been recognized for several decades as an essential tool for conserving biodiversity. The impacts of climate change now give them a renewed role as adaptation tools for a changing climate. Their importance in this respect is threefold:

- in supporting species to adapt to changing climate patterns and sudden climate events by providing refuges and migration corridors;
- in protecting people from sudden climatic events and reducing vulnerability to floods, droughts and other weather-induced problems;
- indirectly, in supporting economies to adapt to climate change by reducing the costs of climate-related negative impacts.

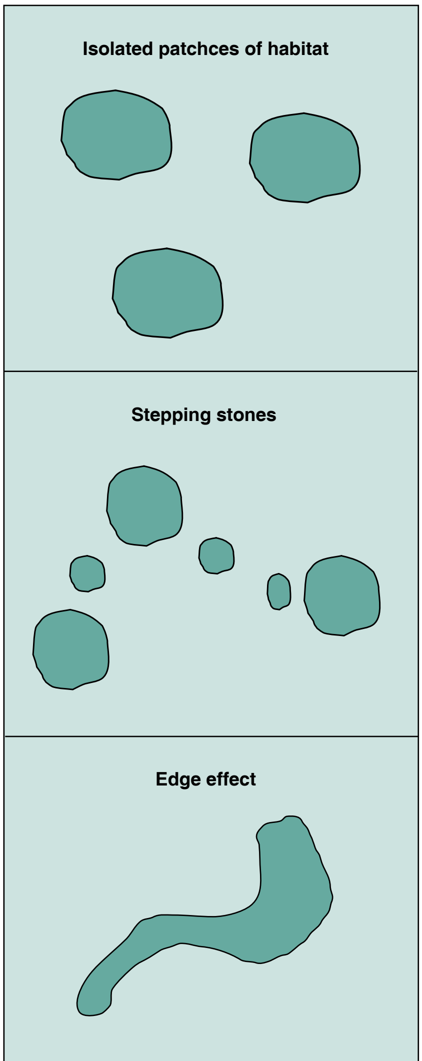
Ecological role

The world now has over 100 000 protected areas, of which the terrestrial ones cover 12.2 percent of the earth's surface (UNEP-WCMC, 2008). Protected areas can be among the most effective tools for protecting species from extinction and from the impact of human-induced threats. If well planned and managed, they can contribute to biodiversity conservation by:

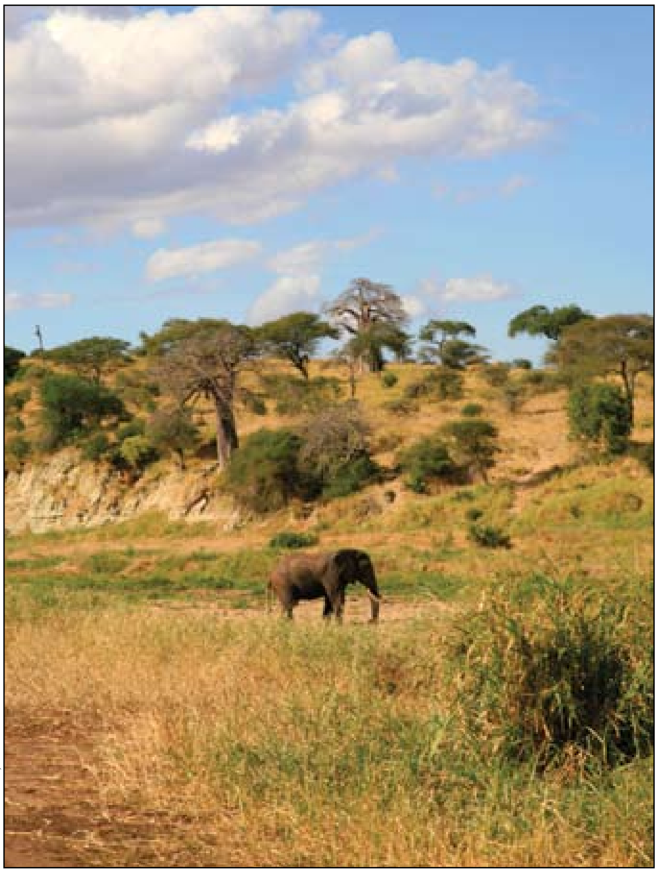
- representing distinct natural communities within conservation landscapes and protected areas networks;
- maintaining ecological and evolutionary processes that create and sustain biodiversity;
- maintaining viable populations of species;
- conserving blocks of natural habitat large enough to be resilient to large-scale disturbances and long-term changes (Noss, 1992).

In the creation of most protected areas and in the identification of sites that achieve targets for habitat and species representation to date, a relatively constant climate has been assumed (Hannah *et al*., 2007). However, as the climate changes, plans and assumptions about protected areas need to be reconsidered (McCarty, 2001). Areas for future conservation efforts need to be assessed in the face of different climate change

Protected areas in a landscape



Source: Adapted from Bennett, 1998.



A. BELOKUROV, IMAGENATURE

Because of the added threat of climate change to African elephants and their habitat, the WWF Species Action Plan for African elephants includes climate vulnerability assessments for elephant populations (Tarangire National Park, United Republic of Tanzania)

scenarios, and the current protected area network needs to be reviewed to ensure that it can deliver intended conservation results and help mitigate negative climate change impacts.

In a changing climate, protected areas will take on added importance as safe havens for biodiversity by offering good-quality habitats less vulnerable to climate extremes, by providing refuges for threatened species and by conserving important gene pools. It will also become more important to protect reference landscapes – ecosystems on which restoration planning is based, and which provide a basis for evaluating the success of restoration (Sayer, 2005).

Networks of protected areas within large-scale landscapes will help accomplish the fourth point above, providing resilience to climate change. Landscape planners can help biodiversity adapt to changing conditions by carefully defining and managing connections or corridors between protected areas, removing or preventing barriers such as roads or monoculture plantations of trees or agricultural crops and creating "stepping stones" for particular species (Figure).

To ensure the survival of priority plant and animal species targeted for conservation, it will be important to obtain new information on their:

- sensitivity to disruptions (e.g. by roads, agriculture, settlements);
- sensitivity to edge effect, i.e. the ratio between perimeter and area (generally the greater the ratio, the greater the sensitivity to disturbances from outside the perimeter);
- food specialization and availability;
- habitat quality required (e.g. primary or secondary forest);
- movements, particularly when under stress;
- migration habits and routes;
- relationship to local human communities and to other species (Mansourian, 2006).

This information can then be overlaid with predicted climate scenarios so that action can be taken to safeguard biodiversity.

For example, because of the added threat of climate change to African elephants and their habitat, the implementation of the WWF Species Action Plan for African elephants (Stephenson, 2007) will include climate vulnerability assessments for elephant populations using available assessment tools (Hannah, 2003). The results will be used to develop and implement climate change adaptation strategies for elephant landscapes identified as being at high risk. The Amazon's unique biodiversity is also expected to be under significant threat from climate change; a loss in the viability of numerous plant species, specifically in the northeastern Amazon, is expected by 2095 under all climate scenarios (Miles, 2002).

Social role

Protected areas may provide ecosystem services such as drinking water, carbon storage and soil stabilization; harbour sacred sites for different faith groups; and hold important gene reservoirs of value in medicine, agriculture and forestry. In the face of climate change these roles all become more critical to enhance the adaptive capacity of local people to cope with climate change (Simms, 2006).

Protected areas, by helping to maintain natural ecosystems, can contribute to physical protection against major disasters, which are predicted to be on the rise with climate change (Scheuren *et al*., 2007). Although the scale of disasters generally depends on an aggregation of factors (e.g. building regulations, land use), in many cases ecosystem maintenance and forest protection can greatly reduce their impacts. Coastal mangroves, coral reefs, floodplains and forests may

Protection of coastal mangroves can help ensure their provision of physical defence against major disasters, which are predicted to be on the rise with climate change (Sundarbans National Park, Bangladesh)

buffer land, communities and infrastructure against natural hazards. For example, during the Indian Ocean tsunami in 2004, vegetation-covered coastal sand dunes at Yala and Bundala National Parks in Sri Lanka completely stopped the waves and protected the land behind them (Caldecott and Wickremasinghe, 2005). Some protected areas also provide an opportunity for active or passive restoration of traditional land use practices such as agroforestry and crop terracing, which may help mitigate the impacts of extreme weather events in arid lands, for example by reducing the risk of erosion and by maintaining soil structure (Stolton, Dudley and Randall, 2008).

In addition, protected area management can help empower marginalized human populations or community groups. Alternative forms of protected area governance such as community conservation or joint management, for example, are being implemented to reduce conflicts over land and to promote long-term maintenance of protected areas for provision of benefits to stakeholders. A case in point is the "Parks with People" policy developed in Bolivia in 2005 to engage indigenous communities in management of protected areas (Peredo-Videa, 2008).

Economic role

If a country's natural habitat is destroyed by climate change impacts, its economy will suffer. A recent study (Dasgupta *et al.*, 2007) found that the gross domestic product (GDP) of a number of countries, led by Viet Nam, could be negatively affected by sea level rise, saltwater intrusion and natural disasters attributed to climate change. In helping to protect natural habitat, protected areas indirectly help to protect the national economy.

In addition, protected areas can provide a direct means of enhancing revenue, notably through tourism, but also through the valuable products they harbour and the services they provide. For example, Guatemala's Mayan Biosphere Reserve provides employment for over 7 000 people and generates an annual income of approximately US$47 million (PCLG, 2002). In Madagascar, a study of 41 reserves found that the economic rate of return of the protected area system was 54 percent, essentially from watershed protection and to a lesser extent from ecotourism (Naughton-Treves, Buck Holland and Brandon, 2005). Thus, protected areas provide a safety net which can be valuable in times of stress, such as extreme climate events.

The loss of protected areas may lead to significant costs, for example infrastructure damage and human tragedy caused by desertification or tsunamis, or to loss of revenue, from tourism for instance. Furthermore, deforestation of major forest blocks, such as the Amazon, is thought to have an impact on global rainfall, which in turn affects agriculture and therefore the livelihoods of millions of people (Nepstad, 2007). Protected areas therefore not only help protect biodiversity, but also indirectly contribute to the planet's food security.

PROTECTED AREA MANAGEMENT AND POLICY RESPONSES

Protected area managers, and the broader conservation community, will need to consider climate change in considering future management actions. Already, most conservation agencies have taken on board the need to factor climate change into their planning. For example, in 2008 WWF embarked on a new global conservation strategy (WWF, 2008a) which includes not only biodiversity goals but also a major focus on humanity's "ecological footprint" (demand on the biosphere in terms of the area of biologically productive land and sea required to provide the resources used and to absorb the waste produced by society). Addressing climate change is a key objective.

In addition to using the creation of protected areas and the number of hectares of threatened habitat under protection as indicators for measuring progress in achieving conservation goals, protected area management will need to address the following additional dimensions to take account of climate change.

Designing protected areas in landscapes

A well-planned protected area network is necessary if species that are present in few fragmented patches of habitat, in small numbers or at the limits of their range are to adapt to climate-related changes. Size, shape and altitudinal gradients all contribute to a protected area's resilience to climate change and to species' freedom of movement. Optimally designed protected area networks should reduce barriers and obstacles between protected areas. They should incorporate buffers, connections, corridors and

A. BELOKUROV, IMAGENATURE

The potential loss of protected areas may lead to loss of revenue, from tourism for example (Iguazu Falls National Park, on the border between Brazil and Argentina, one of the top destinations in South America with nearly 2 million tourists a year)

stepping stones for the movement of animal species across the landscape and abundant good habitat across a vast range of altitudes, so that in times of stress species can move to more favourable environments within the relative safety of a protected area. In Borneo, for example, WWF and partners are seeking to secure a network of protected areas in a 240 000 km^2 landscape which has an altitudinal gradient of more than 4 000 m, to enable species to move between different habitat types (WWF, 2008b).

Expanding the protected area network

In seeking to maintain a representative network of ecosystems, it is no longer safe to assume that all of a species' historic range remains suitable in a changing climate. As noted above, under future climate scenarios many of the current protected areas will no longer be able to fulfil their role of protecting representative habitat for species targeted for conservation. A modelling study in Mexico, the Cape region of South Africa and Western Europe indicated that with a moderate increase in temperatures, extensive new protected areas would be needed to achieve representativeness (Hannah *et al*., 2007). In this regard the Convention on Biological Diversity's Programme of Work on Protected Areas (CBD, 2004) urged great expansion of the protected area network across the globe to secure long-term representativeness of ecosystems and help species adapt to climate change. In subsequent years the world's protected areas have expanded exponentially, but the expansion needs to continue.

Managing protected areas in landscapes

Effective management is essential to climate adaptation. Protected area management to ensure adaptation to climate change may include restoration, focusing on resilient habitats, managing specifically for anticipated threats such as fire and pests, and addressing other threats (which can be exacerbated by climate change). Restoration will be important both within protected areas and around them in targeted locations within the wider landscape. WWF adopts a forest landscape restoration approach in which key elements of the landscape are identified for restoration to achieve multiple objectives and make the whole landscape more functional in meeting environmental, social and economic objectives (Mansourian, Vallauri and Dudley, 2005). In the lower Danube basin in Bulgaria, for example, WWF and partners have focused on restoring floodplain forests to ensure that this biological corridor, important for spawning fish as well as nesting and migratory birds, can withstand climate change (WWF, 2002). Since ancient habitats that have withstood variations in climate to date may be more likely to endure future changes, WWF is also working with local authorities in Chile to ensure protection of the resistant Valdivian forest which has trees over 3 000 years old.

In a future stressed by climate change, protected areas will only be viable if they are directly relevant to human communities that live in or depend on them (sustainable honey production by a local women's group in a forest reserve in Zambia)

A. BELOKUROV, IMAGENATURE

Future protected area management strategies and plans should also include options for carbon storage as well as reducing emissions from deforestation and degradation. Regular assessments of management must be a priority so that interventions can be adjusted if necessary.

Socio-economic considerations

In a future in which more people will be vying for fewer resources, and where climate change is likely to cause a greater strain on both people's livelihoods and the availability of resources, protected areas will only be viable if they are directly relevant to human communities that live in or depend on them (Borrini-Feyerabend, Kothari and Oviedo, 2004). Protected areas contribute less to livelihood strategies in practice than they could in theory. In the future, design and management plans for protected areas will need to focus more on local community engagement, linkages with the national development agenda and alternative forms of protected area management such as private-sector or community management. Governance schemes for protected areas may need to be modified for greater effectiveness and for conflict resolution. Decision-makers need to ensure that institutional and legal conditions enable people to benefit directly from protected areas.

CONCLUSIONS

While future climate change scenarios and local impacts remain uncertain, protected areas will surely be affected. However they can also play a significant part in adaptation to climate change. Improving climate resilience and adaptation will require changes in the approach to protected area planning, establishment and management. Moreover, it is critical to reduce global greenhouse gas emissions and to keep the temperature rise within a 2°C limit. If these are not achieved, adaptation will never be sufficient. ◆

Bibliography

Bennett, A. 1998. *Linkages in the landscape: the role of corridors and connectivity in wildlife conservation.* Gland, Switzerland, World Conservation Union (now International Union for Conservation of Nature) (IUCN).

Borrini-Feyerabend, G., Kothari, A. & Oviedo, G. 2004. *Indigenous and local communities and protected areas: towards equity and enhanced conservation.* Gland, Switzerland & Cambridge, UK, IUCN.

Caldecott, J. & Wickremasinghe, W.R.M.S. 2005. *Sri Lanka: post-tsunami environmental assessment*. Nairobi, Kenya, United Nations Environment Programme (UNEP).

Convention on Biological Diversity (CBD). 2004. *Programme of Work on Protected Areas*. Montreal, Canada.

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D & Yan, J. 2007. *The impact of sea level rise on developing countries: a comparative analysis*, World Bank Policy Research Working Paper 4136. Washington, DC, USA,World Bank.

Dudley, N., ed. 2008**.** *Guidelines for applying protected area management categories*. Gland, Switzerland, IUCN.

Hannah, L. 2003. Regional biodiversity impact assessments for climate change: a guide for protected area managers. *In* L.J. Hansen, J.L. Biringer & J.R. Hoffman, eds. *Buying time: a user's manual for building resistance and resilience to climate change in natural systems*, pp. 235–244. Berlin, Germany, World Wide Fund for Nature (WWF).

Hannah, L., Midgley, G., Andelman, S., Araújo, M., Hughes, G., Martinez-Meyer, E., Pearson, R. & Williams, P. 2007. Protected area needs in a changing climate. *Frontiers in Ecology and the Environment*, 5(3): 131–138.

Intergovernmental Panel on Climate Change (IPCC). 2002. *Climate change and biodiversity*, ed. H. Gitay, A. Suárez, R.T. Watson & D.J. Dokken. IPCC Technical Paper V. Geneva, Switzerland & Nairobi, Kenya, World Meteorological Organization (WMO) & United Nations Environment Programme (UNEP).

IPCC. 2007. *Climate change 2007 – impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge, UK, Cambridge University Press.

Mansourian, S. 2006. *Joining the dots: species and protected areas – A contribution to the CBD Programme of Work on Protected Areas*. Gland, Switzerland, WWF.

Mansourian, S., Vallauri, D. & Dudley, N., eds. 2005. *Forest restoration in landscapes: beyond planting trees.* New York, USA, Springer.

McCarty, J.P. 2001. Ecological consequences of recent climate change. *Conservation Biology*, 15: 320–331.

Miles, L.J. 2002. *The impact of global climate change on tropical forest biodiversity in Amazonia*. PhD thesis, Centre for Biodiversity and Conservation, School of Geography, University of Leeds, Leeds, UK.

Naughton-Treves, L., Buck Holland, M. & Brandon, K. 2005. The role of protected areas in conserving biodiversity and sustaining local livelihoods. *Annual Review of Environment and Resources*, 30: 219–252.

Nepstad, D. 2007. *The Amazon's vicious cycles: drought and fire in the greenhouse.* Gland, Switzerland, WWF.

Noss, R. 1992. The Wildlands Project: land conservation strategy. *Wild Earth*, Special Issue: 10–25.

Peredo-Videa, B. 2008. Climate change, energy and biodiversity conservation in Bolivia – roles, dynamics and policy responses. *Policy Matters*, 16: 163–174.

Pounds, J.A., Bustamante, M.R., Coloma, L.A., Consuegra, J.A., Fogden, M.P.L., Foster, P.N., La Marca, E., Masters, K.L., Merino-Viteri, A., Puschendorf, R., Ron, S.R., Sánchez-Azofeifa, G.A., Still, C.J. & Young, B.E. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature*, 439: 161–167.

Poverty and Conservation Learning Group (PCLG). 2002. *Sustainable harvesting of non timber forest products for the conservation of the biosphere reserve in Guatemala*. Case Study C0035. London, UK, International Institute for Environment and Development (IIED). Available at: www.povertyandconservation.info/biblio/C0035

Sayer, J. 2005. Goals and targets of forest landscape restoration. *In* S. Mansourian, D. Vallauri & N. Dudley, eds. *Forest restoration in landscapes: beyond planting trees*, pp. 101–108. New York, USA, Springer.

Scheuren, J.-M., le Polain de Waroux, O., Below, R., Guha-Sapir, D. & Ponserre, S. 2007. *Annual disaster statistical review: the numbers and trends 2007.* Brussels, Belgium, Centre for Research on the Epidemiology of Disasters (CRED).

Scott, D. 2005. Integrating climate change into Canada's National Parks System. *In* T. Lovejoy & L. Hannah, eds. *Climate change and biodiversit*y, pp. 343–345. New Haven, Connecticut, USA & London, UK, Yale University Press.

Simms, A. 2006. *Up in smoke? Latin America and the Caribbean: the threat from climate change to the environment and human development.* 3rd report, Working Group on Climate Change and Development. London, UK, New Economics Foundation.

Stephenson, P.J. 2007. *WWF Species Action Plan: African elephant, 2007–2011.* Gland, Switzerland, WWF.

Stolton, S., Dudley, N. & Randall, J. 2008. *Natural security: protected areas and hazard mitigation.* Gland, Switzerland, WWF.

United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC). 2008. *State of the world's protected areas*: *an annual review of global conservation progress.* Cambridge, UK,

World Wide Fund for Nature (WWF). 2002. *Forest landscape restoration: working examples from 5 ecoregions*. Brochure. Gland, Switzerland.

WWF. 2008a. *WWF Global Programme Framework 2008–2020.* Gland, Switzerland.

WWF. 2008b. *WWF Heart of Borneo Network Initiative Strategic Plan*. Gland, Switzerland. ◆

Using traditional knowledge to cope with climate change in rural Ghana

B.A. Gyampoh, S. Amisah, M. Idinoba and J. Nkem

A survey of rural communities in the Offin river basin suggests the value of blending traditional and scientific knowledge in strategies for coping with climate change and variability.

After the December 2004 tsunami off the coast of Indonesia, calls multiplied for high-technology solutions (installation of early warning systems using cutting-edge satellite and ocean buoy technologies) to prevent similar disastrous occurrences. Meanwhile news began to circulate about how indigenous communities had escaped the tsunami's wrath by using their traditional knowledge (Box below), drawing attention to the importance of this form of knowledge to natural disaster preparedness and response.

Traditional knowledge – the wisdom, knowledge and practices of indigenous people gained over time through experience and orally passed on from generation to generation – has over the years played a significant part in solving problems, including problems related to climate change and variability. Indigenous people that live close to natural resources often observe the activities around them and are the first to identify and adapt to any changes. The appearance of certain birds, mating of certain animals and flowering of certain plants are all important signals of changes in time and seasons that are well understood in traditional knowledge systems. Indigenous people have used biodiversity as a buffer against variation, change and catastrophe; in the face of plague, if one crop fails, another will survive (Salick and Byg, 2007). In coping with risk due to excessive or low rainfall, drought and crop failure, some traditional people grow many different crops and varieties with different susceptibility to drought and floods and supplement these by hunting, fishing and gathering wild food plants. The diversity of crops and food resources is often matched by a similar diversity in location of fields, as a safety measure to ensure that in the face of extreme weather some fields will survive to produce harvestable crops.

Adaptation to climate change includes all adjustments in behaviour or economic

Indigenous knowledge saves lives

Just before the Indian Ocean tsunami struck in 2004, numerous people were attracted to the shoreline by the unusual spectacle of fish flopping on the sea floor exposed by the sea's withdrawal. Not the Moken and Urok Lawai peoples of Thailand's coasts and islands, the Ong of India's Andaman Islands and the Simeulue community of Indonesia; they all knew to head rapidly inland to avoid the destructive force of the sea. The small villages of the Moken and Ong were completely destroyed, but their inhabitants escaped unscathed. Even more striking was the displacement of more than 80 000 Simeulue people beyond the reach of the tsunami; only seven people died. This surprisingly efficient response, striking in its contrast with the frightening losses suffered elsewhere in Indonesia, was acknowledged by the granting of a United Nations Sasakawa Award for Disaster Reduction to the Simeulue people.

Source: Elias, Rungmanee and Cruz, 2005.

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The River Offin is the main source of water for the communities in the river basin

structure that reduce the vulnerability of society to changes in the climate system (Smith, Ragland and Pitts, 1996). Whether people can adapt, and for how long, depends on the resources available. Africa is the region most vulnerable to the negative impacts of climate change and at the same time has low adaptive capacity. But the people, particularly at the local level, are making efforts to adjust to the changes they observe.

Warming through the twentieth century in Africa has been estimated at between 0.26 and 0.5°C per decade (Hulme *et al*., 2001; Malhi and Wright, 2004). This trend is expected to continue and even to increase significantly, with attendant negative effects on livelihoods. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), a medium-high emission scenario would see an increase in annual mean surface air temperatures of between 3° and 4°C by 2080. This implies difficult times ahead for local people that depend directly on natural resources for their livelihoods and have few assets or technologies to cope with the changes to come.

In Ghana, recorded temperatures rose about 1°C over the last 40 years of the twentieth century, while rainfall and runoff decreased by approximately 20 and 30 percent, respectively (Ghana Environmental Protection Agency, 2000). As a country that depends mainly on rainfed agriculture, Ghana is extremely vulnerable to climate variability and change. But over the years, farmers and other natural resource dependent communities in the country have found varied ways of coping with these changes, based on traditional knowledge and practices.

This article assesses strategies by rural communities in the basin of the River Offin in Ghana to cope with climate change and variability. Their views on climate change and accounts of their means of coping with the changes were collected in 2007 through semi-structured questionnaires, focus group discussions, interviews and field observations in 20 rural communities. Only community members 40 years and above were questioned, on the assumption that younger people would have less experience of climate changes and fewer relevant observations. At most ten questionnaires were administered per community.

Through the focus group discussions and questionnaires, individuals who showed appreciable knowledge of environmental changes around them were selected for in-depth interviews. They were mainly experienced local farmers who could attest to noticeable changes in rainfall and temperature, and traditional elders and leaders who were involved in community decision-making.

THE CONTEXT OF THE OFFIN RIVER BASIN

The Offin river basin has a semi-humid tropical climate and moist semi-deciduous forests. The communities covered in the study are rural and predominantly subsistence farmers. Some are also involved in cocoa farming. Agriculture in this region, as in most parts of Ghana, is rain dependent and the planting seasons parallel the two rainy seasons – the main season from April to July and the minor season from September to October. Livestock rearing is limited. Economic activity is low, although most of the people engage in small-scale trade to augment their low income from agriculture. About 90 percent of the communities covered have no running water and depend on the rivers, streams and rainfall for their water needs.

OBSERVED EFFECTS OF CLIMATE CHANGE IN THE OFFIN BASIN

The indigenous people in the study area may not understand the concept of global warming or climate change, but they observe and feel the effects of decreasing rainfall, increasing air temperature, increasing sunshine intensity and seasonal changes in rainfall patterns. Their observations are corroborated by a study that recorded a reduction in mean annual rainfall of 22.2 percent and a gradual rise in average maximum temperatures of 1.3°C or 4.3 percent from the 1961 to 2006 (Gyampoh *et. al*., 2007).

Partly as a result of reduced rainfall – compounded by deforestation and forest degradation – discharges in all the water bodies in the basin have been low, and some streams have completely dried up (Gyampoh, Idinoba and Amisah, 2008). Flows in the River Offin have decreased from 6.9 m^3 per second in 1957 to 3.8 m^3 per second in 2006 – a 45 percent reduction (Gyampoh *et. al*., 2007). In the dry seasons of 2006 the flow was so low that the river bed was exposed, and some of the wells dug by communities to ensure availability of water year round also

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The River Offin dries up to the river bed during the peak of the dry season, making water scarce

dried up, indicating a possible reduction in groundwater. Water availability is decreasing at a time when the communities' water demand is increasing because of population growth.

Recent crop failures in the basin, especially since 2000, have been attributed to low rainfall, prolonged rainfall shortages and changes in rainfall patterns. Agriculture in the basin is rainfed and farmers have over the years developed ways of predicting the arrival of the rainy season. Farmlands are cleared and prepared in anticipation of the rains to start the cropping season. However, during recent years the beginning of the rainy season has become unpredictable. In some years, the first rains have arrived at the normal time but have been followed by an unexpected long break before resuming. Thus it has become difficult for farmers to plan their cropping seasons to coincide with the rains to ensure maximum crop yield. In addition to the problem of timing, prolonged rainfall shortage has caused drought situations, with reduced water available in the soil for crop growth. The result has been low crop yields or crop failure.

Increasing temperature and intense sunshine, coupled with prolonged rainfall shortages, cause crops to wilt. Some cocoa growers described their trees withering as a result of exposure to intense and prolonged sunshine. Vegetable growers claimed that high temperatures were causing their vegetables to ripen prematurely, decreasing the sale value of their produce.

When crops fail, money spent on land preparation and planting, as well as income from the sale of farm produce, is lost and household savings are spent to replant. People can withstand occasional bad harvests but have trouble coping with consistently bad ones.

Heat and water related diseases are becoming more common in the basin. Malaria incidence has increased, as people are exposed to mosquitoes by sleeping in the open or with their windows open because of unusually high night temperatures. During prolonged rainfall shortages, water sources become scarce, stagnant and contaminated, raising the incidence of diarrhoea and bilharzias. Shingles and other skin conditions, some of which were previously rare in the communities, have also become common during periods of high temperatures, according to those interviewed.

TRADITIONAL COPING STRATEGIES – AND CHALLENGES

The study revealed a variety of coping strategies applied with mixed success, which suggests that local traditional knowledge could provide the basis for development of more effective strategies.

The people in the surveyed communities realize that water shortages are a major threat to their survival and have developed several strategies to adapt to this phenomenon. One is to reuse water, for example from washing clothes or utensils, to irrigate backyard gardens and nurseries. Households are also rationing water, trying to reduce the water use per person per day. However the practice is abandoned as soon as the rains begin. This strategy needs to be part of a behavioural change and not applied only during periods of water shortage.

Most communities are actively reviving rainwater harvesting, a traditional way of collecting and storing rainwater in big barrels placed under the roofs of houses. This practice had largely been abandoned when the communities installed wells and boreholes, but has attracted interest again as a result of their drying up. However most of the communities covered in the study reported that they are unable to harvest enough rainfall under the current climate.

The traditional and local authorities identified clearing of riparian vegetation as a major factor increasing soil erosion and siltation of rivers, which eventually reduces stream flow, and they are adopting measures to remedy the situation. The measures include creating awareness of the effects of deforestation around

Intense sunshine withers cocoa leaves in the absence of shade from trees

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Barrels for collecting rainwater from the roofs of buildings are common in rural households

water bodies, sensitizing the communities about prevention of bush fires, promoting community-based management of forests and imposing fines on those who indiscriminately set fire to the forests, clear riparian vegetation or violate other measures to protect the environment. However, these efforts by the traditional authorities are not yielding notable results because the communities, although still rural in terms of development and infrastructure, have become more cosmopolitan or heterogeneous and no longer adhere as absolutely to traditional authority as they did in the past. The communal nature of the communities is breaking down; people now tend to be more concerned with individual than with collective well-being.

Traditional taboos, such as forbidden days when nobody was supposed to go to the river so the river spirit or god could have a day of rest, once also provided a means of protecting the water bodies. However, the observance of such taboos has declined with modernization and the increasing heterogeneity of the communities. With the widespread adoption of Christianity, traditional spiritual practices are now seen as superstition. Religion is a delicate issue in these communities, and some of the traditional laws, although potentially useful, are not completely adhered to.

As described above, indigenous knowledge in agriculture and water management, acquired over many years of practice, previously helped the communities to cope well with water shortage, droughts and crop damage or losses, but traditional approaches have become difficult to apply in recent years because of changing rainfall patterns. Farmers are adapting to this constraint by planting different crops. Crops that thrive well under the current prevailing conditions are increasingly being planted in areas that previously did not support their cultivation. An example is the shift from cocoa cultivation to drought-resistant crops such as cassava. Vegetable growers are also gradually moving into the river plains where their crops can get more water. These are forms of adaptation but are obviously not sustainable. Cocoa crops, for example, were previously a major source of income for the upkeep of the farmers' families, for the purchase of agricultural inputs and for expansion of their farms. The clearing of riparian vegetation and the use of agricultural chemicals close to the rivers and streams create hazards for the environment and ultimately for the people of the region.

Most farmers recognized the importance of having trees on their farms to shade their crops from intense sunshine. However growing trees had little appeal to them because they had had negative experiences with timber companies (see Box below) and illegal chainsaw loggers trampling their crops. Sustained

Adapting to climate change by planting trees on farms: dispelling a disincentive

Until 2002, all timber trees in Ghana were owned by the government in trust for the people, and the government could give any area of land in concession to a timber company. Farm crops were sometimes destroyed by timber merchants claiming to have permits to harvest trees in concessions that covered farmlands. To protect their crops, some farmers deliberately killed the trees on their farms; tree planting held little appeal for them.

The Timber Resource Management Amendment Act of 2002 provides that the right to harvest trees and extract timber from a specified area of land shall not be granted if there are farms on the land, unless the consent of the owners of the farms has been obtained, or if timber is already being grown on the land under the ownership of any individual or group of individuals. However this legislation has not significantly changed the relationship between timber merchants and farmers, because most farmers are unable to show clear proof of ownership of trees on their farms (i.e. proof that they either planted the trees or tended them until maturity). Farmers also tend to be uninformed about forest laws and lack the financial strength of timber merchants. However, as a result of efforts by some non-governmental organizations to educate farmers about the forest laws and to help them obtain proper documentation of the ownership of planted trees, some farmers are now beginning to incorporate trees in their farmlands or to protect existing trees.

Because of previous poor legislation and lack of awareness of their current rights, farmers have sometimes killed trees on their farms (by ringing them, for example) to keep timber firms away

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awareness programmes are needed to inform rural farmers of their rights and to empower them to protect their farms and most importantly to plant more trees.

THE WAY FORWARD

The partial success of the use of traditional knowledge in coping with climate change leads to the conclusion that a healthy relationship between scientific knowledge and traditional or indigenous knowledge – which both have their limitations – is desirable, especially in developing countries where technology for prediction and modelling is least developed. Whereas most precipitation models and records mainly focus on changing amounts of precipitation, indigenous people also emphasize changes in the regularity, length, intensity and timing of precipitation. Whether or not scientific models are incorporated into local explanations depends on the status and accessibility of science within a culture and on the influence of the communications media (Salick and Byg, 2007).

To capitalize on, develop, expand and mainstream indigenous adaptation measures into global adaptation strategies, traditional knowledge should be further studied, supported and integrated into scientific research. Incorporating indigenous knowledge is less expensive than bringing in aid for populations unprepared for catastrophes and disasters, or than importing adaptive measures which are usually introduced in a top-down manner and difficult to implement, particularly because of financial and institutional constraints.

There is much to learn from indigenous, traditional and community-based approaches to natural disaster preparedness. Indigenous people have been confronted with changing environments for millennia and have developed a wide array of coping strategies, and their traditional knowledge and practices provide an important basis for facing the even greater challenges of climate change. Although their strategies may not succeed completely, they are effective to some extent and that is why the people continue to use them. While indigenous communities will undoubtedly need much support to adapt to climate change, they also have expertise to offer on coping through traditional time-tested mechanisms. ◆

Bibliography

Elias, D., Rungmanee, S. & Cruz, I. 2005. The knowledge that saved the sea gypsies. *A World of Science*, 3(2): 20–23.

Ghana Environmental Protection Agency. 2000. Ghana's initial national communication under the United Nations Framework Convention on Climate Change. Accra, Ghana.

Gyampoh, B.A., Idinoba, M. & Amisah, S. 2008. Water scarcity under a changing climate in Ghana: options for livelihoods adaptation. *Development*, 51: 415–417.

Gyampoh, B.A., Idinoba, M., Nkem, J. & Amisah, S. 2007. Adapting watersheds to climate change and variability in West Africa – the case of Offin River basin in Ghana. In *Proceedings, Third International Conference on Climate and Water*, pp. 205–213. Helsinki, Finland, Finnish Environment Institute (SYKE).

Hulme, M., Doherty, R.M., Ngara, T., New, M.G. & Lister, D. 2001. African climate change: 1900–2100. *Climate Research*, 17: 145–168.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate change 2007: the physical science basis*, ed. S. Solomon, D. Qin, M. Manning, M. Marquis, K. Averyt, M.B. Tignor, H.L. Miller Jr. & Z. Chen. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK & New York, USA, Cambridge University Press.

Malhi, Y. &Wright, J. 2004. Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philosophical Transactions of the Royal Society Series B*, 359: 311–329.

Salick, B. & Byg, A., eds. 2007. *Indigenous peoples and climate change*. Oxford, UK, Tyndall Centre for Climate Change Research.

Smith, J.B., Ragland, S.E. & Pitts, G.J. 1996. A process for evaluating anticipatory adaptation measures for climate change. *Water, Air and Soil Pollution*, 92: 229–238. ◆

Climate change and non-wood forest products: vulnerability and adaptation in West Africa

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Forest ecosystems in West Africa provide numerous non-wood forest products (NWFPs) including food, medicines and construction materials valuable to rural livelihoods and national economies. In recent years the subregion has experienced concurrent extremes of droughts (a result of reduced rainfall frequency) and floods (often caused by sporadic intense rainfall coupled with reduced forest cover) which have affected the natural regeneration and survival of the resources.

Research carried out by the Tropical Forest and Climate Change Adaptation (TroFCCA) project of the Center for International Forestry Research (CIFOR) in some local communities in northern Burkina Faso indicates significant reduction in the distribution and availability of some NWFP species and high variability in their productivity, making forest-dependent communities more vulnerable. These changes are attributed to rising temperatures and changing rainfall patterns in combination with human activities such as deforestation, agricultural expansion, overharvesting, annual bush fires and overgrazing.

In some locations such as Djomga and Gnalalaye villages, some valuable NWFP-producing tree species (e.g. *Adansonia digitata*, *Diospyros mespiliformis* and *Anogeissus leiocarpus*) have become extinct. Although the extinction of species cannot be linked completely to climate variability and change, the perception of local communities is that recurrent droughts have greatly contributed to changes in species composition – a perception that is in line with findings from Burkina Faso's National Adaptation Programme of Action. The term "climate change" does not exist in the weather lexicon of local communities, but they readily point to reduced rainfall amount, increasing temperatures and the observable differences in weather conditions over the decades, and perceive loss of species as local evidence of climate-induced changes, particularly in Sahelian zones.

Different adaptation measures have been put in place to reduce vulnerabilities through forest management and conservation practices. In Burkina Faso, the government's reforestation and afforestation programme aims at the ecological zoning of tree species following the southward shift in rainfall patterns to facilitate the evolution of the forest ecosystem under current and predicted changes in climatic conditions. Farmers are preserving and protecting particularly useful tree species (e.g. *Vitellaria paradoxa*, *Parkia biglobosa*, *Adansonia digitata*) on their farmlands to ensure a continuous supply of NWFPs. Research institutions in the region (e.g. the Forest Research Institute of Ghana, the Institut de l'Environnement et de Recherches Agricoles and the Centre National de Semences Forestières in Burkina Faso, and the Forestry Department of the Institut d'Économie Rurale in Mali) are improving the resistance and adaptation of useful tree species to recurrent droughts and bushfires.

The major constraint to the effectiveness of these measures is the inadequate supply of improved planting materials because of insufficient financial resources. Moreover, the subregion currently lacks a dynamic participatory planning process involving all stakeholders at the local, district and national levels, using a forest ecosystem approach with continuous monitoring and evaluation, which is needed for effective adaptation.

For more information on the work of TroFCCA in West Africa, see: www.cifor.cgiar.org/trofcca/_ref/africa/index.htm

F. BATIONO

Reforestation of* Euphorbia balsamifera*, a source of medicinal products, in Dori, Burkina Faso

Climate change impacts on goods and services of European mountain forests

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A review of likely ecosystem sensitivities and impacts on forest products and services from expected climatic changes in European mountain forests – and possible adaptation options.

European mountainous areas, in contrast to many other mountain regions of the world, have high population densities and consequently many potentially conflicting demands on the environment. Forest ecosystems are key elements in the land-use matrix of these areas, providing a variety of goods and services to human livelihood. Expected climate change, however, could place these ecosystem services at risk because of the high exposure of European mountain ecosystems.

In the Alps, for instance, the observed total temperature increase over the second half of the twentieth century was roughly twice the global average. Regional projections from state-of-the-art climate models indicate that this trend will continue in the twenty-first century, with an expected warming of approximately 3.5 to 4°C in summer and little less in other seasons between today and 2100 (Christensen *et al.*, 2007). Changes in precipitation and windstorm patterns are still highly uncertain and will be strongly influenced by the local geomorphological heterogeneity of mountainous landscapes. In central European mountain areas precipitation patterns are expected to shift towards more moist conditions in winter and increasingly dry summers. This trend is projected to be even stronger in the Mediterranean, where distinct decreases in precipitation during the vegetation period are expected

Mountain forests provide multiple goods and services to local communities, for example in the Stubai Valley in the Central Alps, Austria

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to be amplified by warming of up to 4°C by the end of the twenty-first century (Christensen *et al.*, 2007).

This article reviews ecosystem sensitivities, future impacts on goods and services and possible adaptation options in relation to expected climatic changes in temperate and Mediterranean mountain forests in Europe. It focuses on the main mountain ranges in these climatic zones – the Alps, Carpathians and Pyrenees – and covers a variety of (current) forest types, ranging from thermophilous broadleaved evergreen and dry coniferous forests to alpine coniferous forests and temperate continental deciduous forests. It is part of a recent in-depth pan-European synthesis on climate change and forestry (Lindner *et al.*, 2008).

Subalpine **Picea abies** *forest infested with the bark beetle* **Ips typographus***, which has already benefited from temperature changes and increasing drought stress, which make host trees more susceptible (inset: characteristic larval galleries of* **I. typographus***)*

R. SEIDL

FOREST ECOSYSTEM SENSITIVITIES

Changes in temperature, water availability and disturbance regimes are likely to lead to changes in productivity of forest ecosystems, particularly in those already limited by either temperature or water. An increased atmospheric CO_2 content may also influence productivity, but the effect on different tree species is not yet fully known (Körner *et al.*, 2005).

At higher elevations, warmer temperatures and less harsh environmental conditions have already resulted in higher growth rates. Continuing lengthening of the vegetation period might intensify this effect, but might also stimulate earlier budburst which could increase the susceptibility of trees to late frosts. Nevertheless, a positive growth trend is expected to continue, particularly at sites not restricted by water availability (Bolli, Rigling and Bugmann, 2007).

At low elevations and in dry inner alpine valleys, changing precipitation patterns and increasing temperatures may result in drought stress, which could decrease productivity. This has already been observed recently, for instance in the upper Rhône Valley in Switzerland (Rebetez and Dobbertin, 2004).

An increase in drought stress might also increase vulnerability of mountain forests to biotic disturbance agents, with implications ranging from increased tree mortality at the stand level to drastic consequences on a larger scale as the system's resilience is exceeded (Raffa *et al.*, 2008).

Warmer and drier conditions also make alpine forest ecosystems more prone to abiotic damage. Periods of drought, especially during winter and spring, promote forest fires, which are expected to increase not only in the already arid and fire-influenced Pyrenees but also in the Alps, where wildfires have been of only minor importance historically (Reinhard, Rebetetz and Schlaepfer, 2005; Schumacher and Bugmann, 2006). While the influence of climate change on storm frequency and severity is still uncertain, the greater number of disastrous storm events in Central Europe over the past two decades (e.g. "Viviane" in 1990, "Lothar" in 1999, "Kyrill" in 2007) underlines an increasing susceptibility.

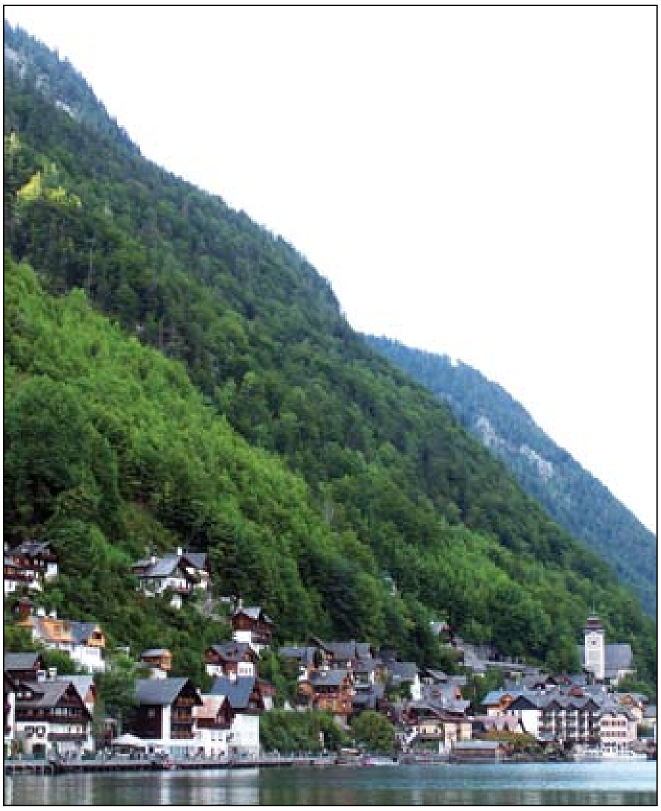
Abiotic damage is a main factor contributing to the risk of biotic disturbance, such as infestation by defoliators (e.g. Battisti, 2004) and mass outbreaks of secondary species of bark beetles (Nierhaus-Wunderwald and Forster, 2000). Norway spruce (*Picea abies*) forests impaired by drought stress or windthrow are highly predisposed to attack by the spruce bark beetles *Ips typographus* and *Pityogenes chalcographus*, which also benefit from increased summer and winter temperatures (Wermelinger, 2004). At present the spatial distribution of the host tree species extends beyond the beetles' thermal range, but the upward shift of climatic conditions that are beneficial to the insects will presumably trigger bark beetle outbreaks in coniferous forests at high elevations (Seidl *et al.*, 2009).

Although development of many poikilotherm organisms (organisms with body temperature that varies with the surrounding temperature, e.g. insects) is positively correlated with rising temperatures, negative effects are possible for certain pest species. Increased winter temperature may impair the inhibition or maintenance of diapause (a dormant state enabling arthropods to survive unfavourable conditions), raise mortality rates of overwintering stages or prevent synchrony between hosts and herbivores (Bale *et al.*, 2002; Battisti, 2004). For example, in Switzerland peak population densities and thus the incidence and intensity of severe outbreaks of the larch bud moth, *Zeiraphera diniana* (a cyclical defoliator of inner alpine larch stands) have been diminishing over the past 30 years in coincidence with the trend of climatic warming, probably owing to increased egg and larval mortality (Esper *et al.*, 2007).

Overall, simulation studies have indicated that the niches of forest tree species are highly sensitive to climatic changes; as a result species distribution and composition may be altered. In the Alps and the Carpathian Mountains the potential area of broadleaved tree species is expected to increase relative to conifers (Lexer *et al.*, 2002; Skvarenina, Krizova and Tomlain, 2004). In the Montseny Mountains in Spain, for instance, the distributions of *Quercus ilex* and *Fagus sylvatica* have already shifted towards higher elevations during recent decades (Peñuelas *et al.*, 2007). The tree line will also rise where suitable microsites become available as a result of decreased tree mortality and increased growth and reproduction where temperature is currently limiting. For example, upward movement of tree lines dominated by *Picea abies* and *Pinus cembra* in the Alps has already been observed in recent years. However, tree lines are sensitive not only to changes in climate but also to land-use changes which may either offset or amplify climatic effects (Gehrig-Fasel, Guisan and Zimmermann, 2007).

POTENTIAL IMPACTS ON FOREST GOODS AND SERVICES

The forest ecosystem sensitivities described above will have considerable impacts on mountain forest goods and services. Timber production will be altered not only by changes in productivity, but also by possible losses due to abiotic and biotic disturbance events, particularly in coniferous stands in the Alps and Carpathians (Seidl *et al.*, 2009). However, climate change will also broaden the silvicultural portfolio in many mountain forest ecosystems, relaxing eco-physiological limitations for an increasing number of broadleaved species.



R. SEIDL

Protective forests shelter the Austrian village of Hallstatt in the Northern Calcareous Alps against rockfall, avalanche and debris flow – functions that could be influenced by increased forest disturbance under climate change

The service of carbon sequestration is partly related to changes in productivity. Forests in the Alps are expected to maintain their role as a carbon sink for approximately the first half of the twenty-first century. Later in the century increasing respiration rates and more frequent disturbances may lead to a decrease in carbon sink strength, and forests might eventually even become a source of atmospheric carbon. Ultimately, the socio-economic environment – including the demand for forest biomass, market prices for carbon sequestration and changes in land use – will determine whether European mountain forests will remain a carbon sink (Zierl and Bugmann, 2007).

An important forest service for mountainous regions as well as for adjacent metropolitan areas is the provision of drinking-water. Large-scale disturbances may lead to increased runoff and consequently reduced water storage in catchments. This may result in decreasing water security as well as increased soil erosion, flooding and debris flow activity. Furthermore, accelerated decomposition of organic matter as a result of canopy openings (from disturbances) and increased temperatures may stimulate the leaching of nitrates and other nutrients, diminishing water quality (Jandl *et al.*, 2008). Climate-induced glacier shrinkage could threaten the water balance of some inner alpine regions. Retreating glaciers may no longer be able to balance the river discharge during hot and dry summer months, with reduced water availability as a result (Zappa and Kan, 2007).

Protection against natural hazards such as flooding, debris flow, landslide, rockfall and avalanche is an ecosystem service of high importance in densely populated mountain areas. Net impacts of climate change on this forest function will be a result of the combined effects on forest dynamics and on the magnitude and frequency of such hazardous processes. In general, increasing disturbances such

Tree line dominated by **Picea abies** ***on Mount Speikkogel, Austria is highly sensitive to climatic changes; a rising tree line can be expected to provide stability for greater protection against hazards, but may also influence biodiversity***

as bark beetle infestations, windthrow and fire will have a strong negative impact on protective functions of forests (Schumacher and Bugmann, 2006). Conversely, a rising tree line might support protection against hazards by stabilizing erodible masses, reducing avalanche starting zones, dampening runoff because of increased interception and water consumption, and stabilizing soils through deeper and more intense rooting.

A rising tree line may also influence the conservation of biodiversity. Plant species diversity in the alpine and nival zones is likely to be adversely affected by upward shifts of subalpine forest and shrubland communities, for example the *Pinus mugo* belt in the Alps (Theurillat *et al.,* 1998). In managed forests, however, where biodiversity is strongly influenced by forest management interventions, the increasing competitiveness of species-rich deciduous forest communities at higher elevations may promote overall biodiversity.

OUTLOOK: NEEDS AND OPTIONS FOR ADAPTATION

In many European mountain forest ecosystems, adaptation measures will be required to counteract adverse climate change impacts and maintain ecosystem goods and services. Local biophysical and socio-economic conditions need to be considered in the development of these measures. Thus only a broad set of general options for adapting forest management to climatic changes is discussed here.

The choice of suitable forest reproductive material (i.e. provenances and genotypes) and species adapted to expected future conditions is of paramount importance for sustainable forestry. Expected drought effects can be mitigated by establishing stands with wider spacing and adapting suitable tending and thinning schemes (Spiecker, 2003). In times of changing disturbance regimes, preventive (e.g. pest monitoring) and remedial (e.g. sanitation felling, pest control) forest protection routines are essential to minimize adverse effects of disturbances on the provision of forest goods and services. To sustain the protective function continuous forest cover is important; this requires tending and thinning practices aimed at achieving maximum stability of forest stands and enhancing regeneration. In addition, maintaining structured and continuous forest canopies supports the provision of drinking-water. The implementation of required measures in complex alpine terrain can be supported by improved forest infrastructure (e.g. road network planning). Furthermore, adaptive management options can be supported by reducing other pressures on mountain forest ecosystems such as ruminant browsing and deposition of pollutants. In general, integrated environmental management is necessary in European mountain regions, especially where land-use changes (e.g. the abandonment of high alpine pastures) strongly alter landscape structure.

Implementation of effective adaptation measures is heavily contingent on the availability of human resources and expertise. Yet the knowledge base with regard to European mountain forests is asymmetrical in terms of subject and location. More research has been done on the Alps than, for instance, the Carpathians and Pyrenees. Timber production is the service studied most frequently, while few studies have explicitly addressed impacts of climate change on the provision of high-quality drinking-water, recreation or non-wood forest products. Successful adaptive management will depend on addressing considerable gaps in understanding of climate change impacts on multipurpose mountain forests.

Furthermore, targeted research on the implementation of adaptation strategies is strongly needed. The development and application of climate-smart decision support systems and the involvement of stakeholders can facilitate this process and support the transfer of research to operational adaptation measures. Scientists, policy-makers and practitioners are called to join forces to build the capacity required to face the challenge of sustainable management of mountain forests under changing climatic conditions. ◆

Bibliography

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

Battisti, A. 2004. Forests and climate change – lessons from insects. *Forest*, 1(1): 17–24.

Bolli, J.C., Rigling, A. & Bugmann, H. 2007. The influence of changes in climate and land-use on regeneration dynamics of Norway spruce at the treeline in the Swiss Alps. *Silva Fennica*, 41(1): 55–70.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A. & 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. Cambridge, UK & New York, USA, Cambridge University Press.

Esper, J., Büntgen, U., Frank, D. C., Nievergelt, D. & Liebhold, A. 2007. 1200 years of regular outbreaks in alpine insects. *Proceedings of the Royal Society B: Biological Sciences*, 274: 671–679.

Gehrig-Fasel, J., Guisan, A. & Zimmermann, N.E. 2007. Tree line shifts in the Swiss Alps: Climate change or land abandonment? *Journal of Vegetation Science*, 18(4): 571–582.

Jandl, R., Herman, F., Smidt, S., Butterbach-Bahl, K., Englisch, M., Katzensteiner, K., Lexer, M., Strebl, F. & Zechmeister-Boltenstern, S. 2008. Nitrogen dynamics of a mountain forest on dolomitic limestone – a scenario-based risk assessment. *Environmental Pollution*, 155: 512–516.

Körner, C., Asshoff, R., Bignucolo, O., Hättenschwiler, S., Keel, S.G., Peláez-Riedl, S., Pepin, S., Siegwolf, R.T.W. & Zotz, G. 2005. Carbon flux and growth in mature deciduous forest trees exposed to elevated CO_2. *Science*, 309: 1360–1362.

Lexer, M.J., Hönninger, K., Scheifinger, H., Matulla, C., Groll, N., Kromp-Kolb, H., Schadauer, K., Starlinger, F. & 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 forest inventory data. *Forest Ecology and Management*, 162(1): 53–72.

Lindner, M., Garcia-Gonzalo, J., Kolström, M., Geen, T., Reguera, R., Maroschek, M., Seidl, R., Lexer, M.J., Netherer, S., Schopf, A., Kremer, A., Delzon, S., Barbati, A., Marchetti, M., & Corona, P. 2008. *Impacts of climate change on European forests and options for adaptation*. Report to the European Commission Directorate-General for Agriculture and Rural Development. AGRI-2007-G4-06. Brussels, Belgium.

Nierhaus-Wunderwald, D. & Forster, B. 2000. *Rindenbrütende Käfer an Föhren*. Merkblatt für die Praxis No. 31. Birmensdorf, Switzerland, Swiss Federal Institute for Forest, Snow and Landscape Research (WSL).

Peñuelas, J., Ogaya, R., Boada, M. & Jump, A.S. 2007. Migration, invasion and decline: changes in recruitment and forest structure in a warming-linked shift of European beech forest in Catalonia (NE Spain). *Ecography*, 30(6): 829–837.

Raffa, K.F., Aukema, B.H., Bentz, B.J., Carroll, A.L., Hicke, J.A., Turner, M.G. & Romme, W.H. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. *BioScience*, 58(6): 501–517.

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

Reinhard, M., Rebetetz, M. & Schlaepfer, R. 2005. Recent climate change: rethinking drought in the context of forest fire research in Ticino, south of Switzerland. *Theoretical and Applied Climatology*, 82(1–2): 17–25.

Schumacher, S. & Bugmann, H. 2006. The relative importance of climatic effects, wildfires and management for future forest landscape dynamics in the Swiss Alps. *Global Change Biology*, 12: 1435–1450.

Seidl, R., Schelhaas, M.-J., Lindner, M. & Lexer, M.J. 2009. Modelling bark beetle disturbances in a large scale forest scenario model to assess climate change impacts and evaluate adaptive management strategies. *Regional Environmental Change.* (In press; available at: http://dx.doi.org/10.1007/s10113-008-0068-2)

Skvarenina, J., Krizova, E. & Tomlain, J. 2004. Impact of the climate change on the water balance of altitudinal vegetation stages in Slovakia. *Ekologia Bratislava*, 23(Suppl. 2): 13–29.

Spiecker, H. 2003. Silvicultural management in maintaining biodiversity and resistance of forests in Europe – temperate zone. *Journal of Environmental Management*, 67(1): 55–65.

Theurillat, J.-P., Felber, F., Geissler, P., Gobat, J.-M., Fierz, M., Fischlin, A., Küpfer, P., Schüssel, A., Velluti, C., Zaho, G.-F. & Williams, J. 1998. Sensitivity of plant and soil ecosystems of the Alps to climate change. *In* P. Cebon, U. Dahinden, H.C. Davies, D. Imboden & C.C. Jaeger, eds. *Views from the Alps: regional perspectives on climate change*, pp. 225–308. Cambridge, Massachusetts, USA, MIT Press.

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

Zappa, M. & Kan, C. 2007. Extreme heat and runoff extremes in the Swiss Alps. *Natural Hazards and Earth System Science*, 7(3): 375–389.

Zierl, B. & Bugmann, H. 2007. Sensitivity of carbon cycling in the European Alps to changes of climate and land cover. *Climatic Change*, 85(1–2): 195–212. ◆

Alfred John Leslie (1921–2009)

Alfred (Alf) John Leslie, former Director of the FAO Forest Industries Division, passed away peacefully in Te Awamutu, New Zealand on Saturday, 24 January 2009, approaching his eighty-eighth birthday. He will be greatly missed.

Alf Leslie was a dynamic, inspirational forestry icon with boundless energy and wise and considered counsel. He demanded robust debate and influenced decisions and outcomes in forestry for many decades, not only in Oceania, but around the globe. He set high standards for himself and encouraged others to do the same – to apply knowledge, challenge norms, inspire others, and above all, be accountable for one's own decisions and actions.

Alf was born in Melbourne, Australia in 1921. After high school, he accepted a Victoria Forests Commission cadetship to the School of Forestry, Creswick, Victoria (1938–1940). He saw active service with the Royal Australian Navy in the Second World War. After recuperating from wounds received during the war, Alf was posted to Taggerty with the Victoria Forests Commission before graduating from Melbourne University with a Bachelor of Forestry Science degree in 1949. Jean and Alf were married in 1948.

Alf worked as a forester for the Victoria Forests Commission (1949–1951), then as Wood Superintendent and Chief Forester with Australian Paper Mills (1951–1958) in Victoria, Australia, which gave him a sound field perspective, particularly in plantation forestry.

Alf Leslie's international career started when he was recruited by FAO to serve as Senior Lecturer at the University of Ibadan, Nigeria (1964–1966). After a brief stint back in Australia at the Forest Research Institute, Canberra (1966–1968), Alf pursued further international challenges as Forest Economist at FAO headquarters in Rome (1968–1974), and later returned to Rome as Director of FAO's Forest Industries Division (1977–1981), serving with distinction before retiring initially to Australia and ultimately to New Zealand. With his relentless energy he continued to write and to consult for FAO and the International Tropical Timber Organization (ITTO) until 2008.

Alf was a prolific writer and had an uncanny ability to communicate what he knew; many of his works have become classics in their field. He enjoyed challenging and inspiring young minds. He taught at the University of Melbourne, Victoria, Australia (1958–1964) while completing a master's degree in Forestry Science. He was reader at the University of Canterbury, Christchurch, New Zealand from 1974 to 1976, and was guest lecturer at the University of Oxford, United Kingdom and at Australian National University. He supervised many Ph.D. theses over the years. In recognition of his services to international forestry, Alf was awarded an honorary doctorate in Forestry Science from the University of Melbourne in 1994.

In 2001, he was awarded the Commonwealth Forestry Association Regional Medal for his contributions to forestry worldwide. Additionally, in 2007, he received the International Forest Engineering Achievement Award from the Council of Forest Engineering. Alf also served as President of the International Union of Societies of Foresters.

Alf challenged conventional views; at a time when most foresters were concerned with how to do things in forestry, he was concerned with the why. But he also deeply respected the work of his predecessors; he felt that foresters would be better equipped to deal with the future if they had a better understanding of the past. A man of broad interests, he lamented the increasing specialization of modern society.

As a young forester, I was privileged to witness Alf's keynote address at the 1980 Australia–New Zealand Institute of Foresters Conference, where he spoke after the Prime Minister of New Zealand. The theme was the future of plantation forestry in New Zealand. Alf commenced his speech by asking, "The future according to whom? the government? the Forest Service? the private sector? environmentalists? or the public?" His address stimulated debate not only at the time but through the following decades, through the reform of the forest sector in New Zealand, the sale of State assets to the private sector and the segregation of protection and production forest estates.

Alf Leslie planted rich and challenging ideas in the minds of young foresters. It is thus a fitting tribute that his family and colleagues from around the globe are contributing to the Alf Leslie Memorial Fund to establish a grove of trees at the School of Forestry, Creswick, Victoria, Australia, which will continue to serve young foresters in their learning. Those wishing to contribute can do so to the following account:

Account Name: LJ Leslie, Alf Leslie Memorial Fund
Account Number: 03-0442-0231527-001
SWIFT Code: WPACNZ2W
Bank Name: Westpac Bank
Bank Address: 98 Alexandra Street, Te Awamutu, 3800, New Zealand

Jim Carle
Chief, FAO Forest Resources Development Service

Biennial gathering of Latin American and Caribbean foresters

The Latin American and Caribbean Forestry Commission (LACFC) held its twenty-fifth session from 29 September to 3 October 2008 in Quito, Ecuador.

A main theme of the meeting was forests and climate change. The commission recognized that climate change provides an opportunity to demonstrate the importance of forests to society, but underlined the need for the forest sector to provide reliable information to contribute effectively to discussion of the issue – noting that with most information on climate change sourced from outside the forest sector, confusion and myths are often generated on the response of forests to climate change. Many delegates agreed that there was a need to step up scientific and technological research in areas relating to forests, with a focus on how climate change affects forest health, vitality and distribution.

Some delegates expressed their concern that eventual mechanisms for support to countries in reducing emissions from deforestation and forest degradation (REDD) might be difficult to access and thus cause frustration, as for forest projects under the Clean Development Mechanism (CDM). The commission emphasized the need to open simple routes to such mechanisms and to facilitate the access of countries to new resources made available by donor countries to finance REDD. In addition, several countries of the region that have extensive forest cover and no major problems of deforestation requested support in encouraging that forms of compensation for the maintenance of their forests be given consideration in deliberations on the second commitment period under the United Nations Framework Convention on Climate Change (UNFCCC).

A session on forest institutions and legislation included presentations from the Central American Commission on Environment and Development (CCAD) and the Amazon Cooperation Treaty Organization (ACTO). The commission noted that decentralization of responsibilities for forest activity is important but needs to be gradual, transparent and responsible; participants underscored the need to prepare local authorities for the functions that they are to assume, by providing them with appropriate capacity, equipment and support.

A session on sustainable forest management highlighted the persistently worrying level of deforestation and forest degradation and evidence of an increase in pests and diseases affecting the region's forests. It drew attention to the region's significant expansion of protected areas, amounting to almost 400 million hectares, and the need for funding for the administration and sustainable management of these areas. A study on exemplary cases of sustainable forest management in Latin America and the Caribbean is currently under way as requested by the previous session of the commission.

Areas in which the commission seeks further support from FAO include identification of new mechanisms for the valuation of forest environmental goods and services in national accounts and new sources of funding for the forest sector, including payment for environmental services and market mechanisms. The Commission also recommended that closer links be established between LACFC and the Latin American Forestry Congress (CONFLAT), held every three years.

The commission expressed its deep concern about the devastating impact of recent hurricanes on Cuba and Haiti and emphasized the need to provide maximum support to those countries to mitigate the negative effects, help restore forest cover and rebuild appropriate living conditions for the affected communities.

Two workshops were held prior to the meeting, on support facilities for national forest programmes and on the outlook for Latin America regarding REDD.

Guatemala will host the twenty-sixth session of LACFC in 2010.

For the full report of the twenty-fifth session, see: www.rlc.fao.org/es/comisiones/coflac/2008/

First European Forest Week

The first European Forest Week was observed 20–24 October 2008, in conjunction with the joint meeting of the thirty-fourth session of the FAO European Forestry Commission and the sixty-sixth session of the United Nations Economic Commission for Europe (UNECE) Timber Committee.

Organized jointly by FAO, UNECE, the Ministerial Conference on the Protection of Forests in Europe (MCPFE) and the French Presidency of the European Union, European Forest Week represented an effort to expand forest sector collaboration in the region. Main events were conducted both at FAO headquarters in Rome and by the European Economic and Social Committee in Brussels, Belgium. Concurrently, over 150 affiliated events took place at the national and local levels in 30 countries across Europe (see Box).

FAO/G.MARCELLI

Hundreds of national and local activities organized for European Forest Week

From Iceland to Turkey and from Portugal to the Russian Federation, over 150 organizations in 32 countries held national and local forest-related events during European Forest Week.

Activities ranged from scientific panel discussions on forests and climate change to outings for children. Activities included cultural events, pedagogic activities, policy meetings, nature excursions, press events and tree planting. An interactive function on the European Forest Week Web site allowed organizers to share information about their events throughout the region. The result was a striking array of activities celebrating the contributions of forests to people's daily lives.

An association in Latvia, for example, organized an information campaign on the role of wood in climate change mitigation, targeting private citizens building or renovating homes as well as decision-makers and the media. The goal was to enhance knowledge of the role of forests and wood products in sequestering carbon dioxide and the importance of wood as a natural and renewable resource for sustainable construction and the creation of a healthy living space. The Finnish Timber Council hosted a seminar entitled "Made of Wood Day" for builders and architects, treating current issues in wood architecture, wood construction and wood research. The Private Forest Centre in Estonia held courses for private forest owners. In Belgium, the Dendronautes offered a tour to the heart of the Ardennes led by sprites, elfs, druids, gnomes and troubadours. In Germany, offers included tree climbing lessons and a chance for children to make "land art" in the forest. The Iceland Forest Service launched a search for the country's biggest tree, and an association in Belarus hosted a conference on forests and foresters in literature.

To view all postings, see the European Forest Week Web site in-Country Activities page at: www.europeanforestweek.org/50790

At FAO headquarters in Rome, representatives of government, intergovernmental organizations and non-governmental and research organizations as well as private forest owners shared perspectives and solutions to global challenges, with emphases on forests and climate change, bioenergy and water. Approximately 400 participants from 45 countries attended.

Complementing the plenary sessions were policy dialogues and partner events on subjects such as improving forest law enforcement and governance in the European Neighborhood Policy, the new forest policy of the Russian Federation, gender and forestry, the role of wood products in climate change mitigation and adaptation of forest trees to climate change. A special workshop was held on the role of wood in green building.

In Brussels, a day-long conference was held on the role of forests and the forest-based sector in meeting the European Union's climate commitments.

New programme supports forest law enforcement, governance and trade in ACP countries

In November 2008, FAO launched a four-year programme, funded by the European Commission, to support forest law enforcement, governance and trade (FLEGT) in African, Caribbean and Pacific (ACP) countries (a group of almost 80 countries involved in cooperation with the European Union under the Lomé Convention).

Illegal logging and associated timber trade result in political, socio-economic and environmental problems in many countries in these regions. In addition to undermining the rule of law, principles of democratic governance and respect for human rights, these practices weaken the competitiveness of legitimate forestry operations and limit their ability to contribute to sustainable forest management. They impair livelihood opportunities for local people and lead to loss of biodiversity and damage to watersheds and other forested ecosystems.

The new programme will support:

- collection, analysis and sharing of FLEGT-related information and knowledge;
- strengthening of legal frameworks;
- strengthening of FLEGT-related institutions;
- pilot projects that create added value and bridge critical gaps in FLEGT processes.

The programme will operate on demand from countries. Targeted calls for proposals will be issued twice a year. The programme is open to all ACP countries, but priority will be given to proposals from countries with significant domestic, regional or foreign trade in forest products. In principle, the programme will not finance 100 percent of the costs of activities; recipient organizations are expected to provide financial or in-kind contributions. The programme will emphasize information and knowledge management and sharing of lessons learned to ensure broad impact and sustainability.

All relevant forestry organizations in ACP countries – government institutions, civil society organizations and private sector organizations – will be eligible for support. Proposals from the latter two must be supported by official requests from the governments concerned. Proposals will be appraised by an expert panel and selected by an Executive Committee, and the selection will be validated by a Steering Committee including representatives of the ACP Secretariat, the European Commission, FAO and any other donors.

Registration opens for XIII World Forestry Congress

The XIII World Forestry Congress will be held in Buenos Aires, Argentina from 18 to 25 October 2009 under the theme "Forests in development: a vital balance". The congress will include presentations, discussions, business meetings and exhibits, as well as two high-level round-tables dealing with climate change and bioenergy. More than 2 500 abstracts have been received from all regions of the world.

Registration

Online registration opened on 1 February 2009. Special prices are available for participants from low- and middle-income countries and for those who register before 30 June. Discounts are available for groups, students and retirees.

In addition, the organizers of the congress are making efforts to guarantee balanced attendance from all regions of the world by offering scholarships to participants from developing countries. Priority will be given to those who have submitted an abstract. Instructions for scholarship application can be found on the congress Web site.

International forestry exhibition

An international forestry exhibition will provide a meeting place for promoting knowledge and awareness for sustainable forest management. The exhibition should be of special interest to producers, wholesalers and retailers of wood and non-wood forest product; suppliers of tools and other inputs; logistics and distribution firms; governmental and international organizations and cooperation agencies; and non-governmental organizations, associations and institutions.

Online booking for stands at the exhibition opened on 1 February 2009.

Side events

Specialized agencies, countries and institutions are welcomed to organize side events related to the seven thematic sessions of the World Forestry Congress. These events will offer participants opportunities for wider discussion and reflection, networking and dissemination of key messages.

The deadline for the reception of applications for side events is 31 March 2009. Side events can be scheduled for a maximum of two hours. Only one application per organization will be considered. Simultaneous interpretation and catering services are available. Terms, conditions and rates are available on the congress Web site.

Business meetings

Space will be made available for organizing business meetings. These will offer opportunities to forest and wood processing industries to establish new business networks or strengthen existing contacts. For more information please contact the Secretariat at: info@cfm2009.org

A small Project Management Unit based at FAO headquarters will be in charge of the day-to-day management of the programme and coordination with the ACP Secretariat and the European Commission.

For further information, contact: Eva.Muller@fao.org

International conference on forests and water

What is the relationship between forests and water, life's most precious resource? This was the subject of the international scientific conference Water and Forests: A Convenient Truth?, held in Barcelona, Spain on 30 and 31 October 2008. Experts from research, policy and academic institutions discussed the interrelation between the two sectors in the context of global change, with increased temperature, uncertain rainfall, changes in land use, increasing populations and a growing demand for water.

Themes examined by the conference included:

- the influence of forest management practices on water yield, for example through the use of a mix of different tree species

of varying ages or the design of forest structure and open areas;
- the capacity of trees planted in agricultural and urban areas, on runoff pathways or in riparian zones to reduce the biochemical impact of pollutants on the environment;
- the extent to which forest canopies and roots protect soil and reduce erosion rates and sediment delivery to rivers.

Policy recommendations focused on the need to develop synergies in forests and water administrations at the policy and planning level. The conference emphasized a more holistic consideration of the interactions between water, forest and other land uses and of socio-economic factors. It stressed the importance of integrated territorial development at the national and regional levels, linking upstream and downstream processes and benefits.

As the most important areas for further study, participants identified the biophysical interactions between forests and water in different situations and contexts, and the development of effective and efficient models for managing forests and water resources with an integrated approach. Equally important is the need to provide more comprehensive knowledge on the forest/water interface to policy-makers.

The conference was organized by the European Forest Institute, the Centre de Recerca Ecològica i Aplicacions Forestals (CREAF), the Centre Tecnològic Forestal de Catalunya (CTFC), FAO, the Ministerial Conference on the Protection of Forests in Europe (MCPFE), the International Union of Forest Research Organizations (IUFRO), the University of Barcelona, the University of Lleida and Obra Social Caixa Catalunya, with funding from the government of Catalonia, Spain.

For further reading on forests and water see *Unasylva* No. 229 (2007) which was wholly devoted to this theme (www.fao.org/forestry/unasylva).

Support to forest management in Afghanistan

In mountainous and mostly arid Afghanistan, long civil war has compounded the environmental challenges caused by water shortage, soil degradation and overgrazing. Forests, which cover about 1.3 percent of the country, have been damaged extensively by clearing for military purposes, illegal harvesting of timber and unsustainable woodfuel collection. Excessive hunting and habitat degradation have decimated the indigenous fauna. The collapse of the government structure limited control of illegal timber exploitation and trade, and an exodus of trained forest officers left the Directorate of Forests and Rangelands with little capacity for planning, policy development and communication.

Wood, fuelwood and non-wood forest products (NWFPs), especially nuts, herbs and fruits, have traditionally played a vital role in the livelihoods of rural Afghan people. In the eastern provinces, cedar (*Cedrus deodora*) grows above 1 800 m and is harvested for export. The reconstruction of Kabul and other cities damaged during the war will increase the demand for wood for construction.

FAO has been assisting the forest sector in Afghanistan through a series of projects. In 2003, Afghan authorities requested FAO assistance to rebuild the sector in a sustainable way. Following limited emergency support to the forestry sector through tree planting, a technical cooperation project, “Support to the Rehabilitation of the Forestry Sector”, was formulated in 2005 to help develop a broad-based national forest programme. This project helped prepare a forest policy and strategy and formulate a new forest law through a participatory process involving all stakeholders. The forest policy and strategy is fully integrated into the Agriculture Master Plan, which provides the framework for agriculture sector development. Capacity building for the forest administration, the private sector and non-governmental organizations is an important component of the strategy.

Since that project concluded in 2007, FAO has continued to provide assistance for the implementation of the forest policy and strategy and field testing of the new forest law. A new project, “Improving Sustainable Livelihoods and Food Security in Afghanistan”, includes a component on participatory forestry to support sustainable livelihoods. The activities will focus on strengthening institutional capacities, improving technical capacities for managing forests and planting trees, and collecting information on NWFPs and fuelwood supply and consumption.

Although substantial time is needed to change customs and habits, it is expected that when the project ends in 2010, forest institutions will be able to advise communities to manage and use their forests sustainably.

Role of forests in climate management

Enhancing the role of the forest sector in national and international climate change mitigation and adaptation programmes was the subject of the conference Role of Forests in Climate Management: Research – Innovations – Investments – Capacity Building, held in Saint Petersburg, Russian Federation from 4 to 7 October 2008. With 22 percent of the world's forests and more than 70 percent of boreal forests, including half of the terrestrial carbon in the northern hemisphere, the Russian Federation was a particularly fitting setting for discussions on the role of temperate and boreal forest management in the mitigation of and adaptation to climate change.

This was the third time in 2008 that the international community convened to focus on the vital role of the forest sector in the global response to climate change. The conference complemented two previous international conferences: the conference on Adaptation of Forests and Forest Management to Changing Climate with Emphasis on Forest Health: A Review of Science, Policies and Practices (Umea, Sweden, August 2008), covered in detail in this issue of *Unasylva*; and The Roles of Boreal Forests in a Global Context (Harbin, China, September 2008), which emphasized the role of boreal forests in climate change mitigation and adaptation.

The Saint Petersburg conference was co-organized by the Federal Forestry Agency of the Russian Federation, the World Bank and FAO. Over 150 representatives from 30 countries participated in plenary, poster and panel sessions dedicated to research, innovations and technologies, human capacity building and investments.

Conclusions reached included the need for:

- awareness and strengthening of the role of boreal forest management at the national and international levels in the context of future climate agreements;
- quantitative assessments, forecasts and related research, particularly on the role of forests in regional carbon cycles;
- innovation in financial mechanisms and investment partnerships, such as green investment schemes;
- removal of existing barriers for developing and implementing joint implementation projects in the forest sector under the Kyoto Protocol.

Climate change meetings in Poland

The fourteenth Conference of the Parties (COP-14) to the United Nations Framework Convention on Climate Change (UNFCCC) marked the halfway point to the December 2009 deadline for agreeing on a framework for action after expiration of the Kyoto Protocol, as set in the Bali Action Plan in 2007.

COP-14 and the fourth Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (COP/MOP 4) were the central meetings of United Nations Climate Change Conference held in Poznań, Poland from 1 to 12 December 2008. Four subsidiary bodies convened in support of these two main bodies, including the Subsidiary Body for Scientific and Technological Advice (SBSTA). A key event was a ministerial round-table. The events drew over 9 250 participants, including more than 800 accredited members of the media.

The main focus in Poznań was on long-term cooperation after 2012. Important decisions addressed the Adaptation Fund under the Kyoto Protocol, technology transfer, the Clean Development Mechanism (CDM), means available to industrialized countries to achieve their emission reduction commitments (including those in the forest sector), capacity building, national communications and methodological issues.

Progress was also made on reducing emissions from deforestation in developing countries (REDD), which was

Forest Day 2

In parallel with COP-14, the second Forest Day was held at the University of Adam Mickiewicz, in Poznań, Poland, on 6 December 2008. The focus was on the incorporation of forests into climate change mitigation and adaptation strategies at both the global and national levels.

Forest Day 2 was co-hosted by the Government of Poland, the Center for International Forestry Research (CIFOR) and the other members of the Collaborative Partnership on Forests (CPF). Following the positive response to the first Forest Day held during the Climate Change Conference held in December 2007 in Bali, Indonesia, Forest Day 2 brought together nearly 900 participants to study cross-cutting issues including adaptation of forests to climate change; addressing forest degradation through sustainable forest management; capacity building for reducing emissions from REDD; and options for integrating REDD into the global climate regime.

The event also included a poster exhibition and nearly 40 side events with themes including REDD for rural development; indigenous and local community perspectives on forests and climate change; the business case for REDD mechanisms for biodiversity conservation and human well-being; REDD and peatland conservation and restoration; and improving global forest monitoring using accurate satellite imagery.

A summary of Forest Day 2, including points of consensus as well as points of disagreement, was delivered to the Executive Secretary of UNFCCC and made available to negotiators at COP-14. The summary highlighted the need to:

- include forests in climate mitigation and adaptation mechanisms and strategies;
- ensure full inclusion and participation of civil society in international, regional, national and local decision-making processes;
- recognize and respect the rights of women, poor people and indigenous peoples.

addressed both in SBSTA plenary and in numerous contact groups and informal consultations. SBSTA recommendations included a request to the Chair to organize an expert meeting to focus on methodological issues relating to reference emission levels for deforestation and degradation; and methodological guidance to promote readiness of developing countries and further mobilization of resources in relation to REDD, including effective participation of indigenous people and local communities.

Towards a coordinated forest-sector response to climate change

Recognizing the important contribution that forests can make to mitigating climate change, the members of the Collaborative Partnership on Forests (CPF) have drawn up a strategic framework to guide the forest sector's response. The document, launched at the December 2008 climate change meetings in Poznań, Poland, is a voluntary action plan for the global forest sector at large. It supports the United Nations Framework Convention on Climate Change (UNFCCC) process, particularly the Bali Action Plan, as well as the Non-Legally Binding Instrument on All Types of Forests of the United Nations Forum on Forests (UNFF). The framework lays the groundwork for a coordinated forest-sector response to climate change, notably through the widespread adoption of sustainable forest management and its integration into broader development strategies.

CPF is a voluntary alliance of 14 international organizations with substantial programmes on forests. Its objectives are to promote the management, conservation and sustainable development of all types of forests and to strengthen long-term political support for these goals. CPF is chaired by FAO; its other members include the Center for International Forestry Research (CIFOR), the Global Environment Facility (GEF), the International Tropical Timber Organization (ITTO), the International Union for Conservation of Nature (IUCN), the International Union of Forest Research Organizations (IUFRO), the Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification (UNCCD), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), the United Nations Forum on Forests (UNFF), the United Nations Framework Convention on Climate Change (UNFCCC), the World Agroforestry Centre (ICRAF) and the World Bank.

With their broad experience in the promotion of sustainable forest management, forest conservation, poverty alleviation and forest governance, CPF members can facilitate comprehensive approaches to the role of forests in climate change mitigation and adaptation. CPF itself is a mechanism through which members can coordinate their climate-related actions. Bringing together their collective experience in the field of forestry, CPF members will assist countries in preparing for the post-2012 climate regime.

The document highlights six main messages:

- Sustainable forest management provides an effective framework for forest-based climate change mitigation and adaptation.
- Forest-based climate change mitigation and adaptation measures should proceed concurrently.
- Intersectoral collaboration, economic incentives and provision of alternative livelihood opportunities are essential for reducing deforestation and forest degradation.
- Capacity building and governance reforms are urgently required.
- Accurate forest monitoring and assessment help informed decision-making but require greater coordination at all levels.
- CPF members are committed to a collaborative and comprehensive approach to forest-based climate change mitigation and adaptation.

An executive summary and the full text of the CPF Strategic Framework for Climate Change are available at: www.fao.org/forestry/cpf-climatechange

IUCN sets its environment action agenda

Biodiversity underpins the well-being of human societies and their economies. The 2008 World Conservation Congress cautioned that the cost of biodiversity loss is greater than that of the world's current financial problems. The congress, held every four years to plan the work of the International Union for Conservation of Nature (IUCN), was held in Barcelona, Spain from 5 to 14 October 2008 and had more than 8 000 participants.

IUCN is the world's oldest conservation organization, uniting under its umbrella more than 1 000 member organizations and some 10 000 volunteer scientists in more than 150 countries. During the Barcelona meeting, the Members' Assembly elected a new president and council and voted on IUCN's programme of work for 2009 to 2012. The new president is Ashok Khosla, Chairman of Development Alternatives, a social enterprise based in Delhi, India, devoted to promoting commercially viable, environmentally friendly technologies for rural communities in developing countries.

Biofuels were a major focus as members called on governments to develop guidelines and standards for the evaluation of biofuel projects and to regulate and manage the production and use of biofuels to limit negative impacts on people and nature.

The congress endorsed reducing emissions from deforestation and degradation (REDD) to mitigate climate change, as long as it remains just and equitable. A "cast your vote live" workshop was held in which participants were asked several questions relating to REDD. Respondents acknowledged that one REDD recipe does not fit all situations and that different approaches are needed in different contexts.

The rights of vulnerable and indigenous communities also received much attention. The congress initiated an ethical framework to guide conservation activities, applying poverty reduction, rights-based approaches and "do no harm" principles. Members called on governments to take into account human rights implications in all conservation-related activities.

The following are some of the high-profile commitments made at the congress.

- The MacArthur Foundation pledged to invest US$50 million in climate change mitigation and adaptation.
- The Mohammad Bin Zayed Species Conservation Fund will invest €25 million for worldwide biodiversity.
- Russia pledged to protect an additional 80 million hectares.
- Paraguay pledged to achieve zero net deforestation by 2020.
- A group of donors launched the second phase of the Water and Nature Initiative to improve river basin management.

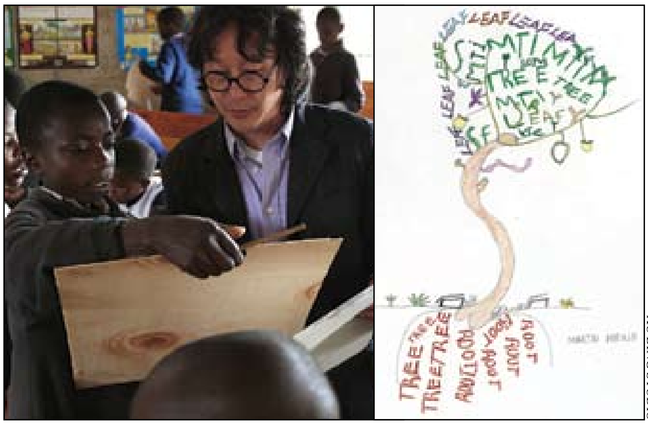
The Indonesian ministries of forestry, environment, interior and public works, ten provincial governors and the global conservation organization WWF announced a commitment to protect the remaining forests and critical ecosystems of the Indonesian island of Sumatra. These forests shelter some of the world's rarest species and provide livelihoods for millions of people. The island has lost 48 percent of its natural forest cover since 1985. More than 13 percent of Sumatra's remaining forests are peat forests, sitting on the deepest peat soils in the world. These soils degrade when cleared and drained, emitting carbon dioxide into the atmosphere.

For more information on the Congress, see: www.iucn.org/congress_08

A Chinese artist and Kenyan children auction artwork to plant trees

A project created by a Chinese contemporary artist is bringing together children, art and the Internet to plant trees in Kenya.

The award-winning art of Xu Bing focuses on the relation between art and the written word. In the Forest Project, the artist leads workshops in Mount Kenya National Park for children from local primary schools. Students combine calligraphy and art



XU BING STUDIO

to make drawings of trees using forms of writing from a variety of cultures and historical periods, including ancient Chinese pictographs, Egyptian hieroglyphs, Cuneiform script, Arabic, English and more.

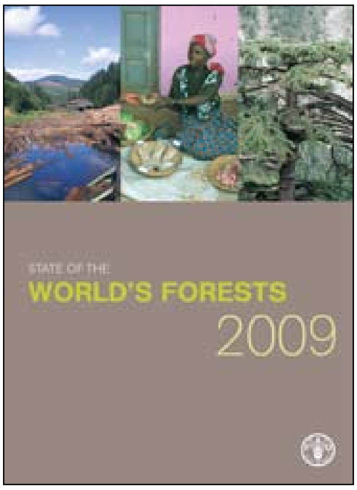
The children's work is then displayed for auction on the Project's Web site. Currently, all proceeds from the sale of student artwork go to the Bill Woodley Mount Kenya Trust, a Kenya-based organization dedicated to preserving the Mount Kenya ecosystem. Xu Bing conceived the Forest Project during a residency at Mount Kenya National Park in 2005.

The income and price disparities between more developed nations and Kenya form the basis for the success of the project. For the cost of a one-way ride on a bus in a developed country, a piece of art created by a student in Kenya can lead to the planting of ten seedlings. The project thus creates a steady flow of funds earmarked for the planting of new trees from developed countries to Kenya.

In addition, selected artwork by the Kenyan students and a large-scale landscape drawing created by Xu Bing are being shown in the exhibit "Human/Nature: Artists Respond to a Changing Planet" at museums in San Diego and Berkeley, California, United States through June 2009.

For more information see: www.forestproject.net

BOOKS



FAO flagship publication looks to the future

State of the World's Forests 2009. 2009. Rome, FAO. ISBN 978-92-5-106057-5.

State of the World's Forests, published biennially, provides a global overview of major developments affecting forests. The 2009 edition, with the theme "Society, forests and forestry: adapting for the future", addresses how the forest sector will be affected by larger changes outside the sector and how it will face the challenges.

Part 1, based on the most recent FAO forest sector outlook studies, examines the collective impact of demographic, economic, institutional and technological changes on forests and forestry in all regions of the world, and outlines emerging scenarios. Important factors that will influence supply and demand of forest products and services include shifts in land dependence, income growth, high food and energy prices and bioenergy production.

Part 2 explores how forestry will have to adapt for the future, with chapters on global demand for wood products and for environmental services, the changing institutional environment for forestry and developments in forest science and technology, including the increasingly recognized role of indigenous knowledge and the need to adapt to challenges of climate change.

The forest sector, like all others, will be affected by the economic crisis that began to unfold as *State of the World's Forests 2009* went to press in late 2008. A postscript entitled "Challenges and opportunities in turbulent times" describes how the slump in demand (especially due to the collapse of the housing sector) and credit squeeze have led to drastic declines in production, consumption and trade of wood products and consequent mill closures and growing unemployment. Even carbon markets have been affected by the downturn. The economic slowdown affects almost all countries, transforming previously upbeat economic forecasts. Although the reduction in demand for some commodities may slow forest clearance, large-scale unemployment in the industrial and services sectors could have negative impacts on forests. On the other hand, the crisis may offer opportunities for sectoral renewal and for paving the way to a greener economy.

In addition to serving as a source of information to support policy and research, *State of the World's Forests 2009* will help to stimulate critical thinking and debate about the future of the world's forests and how the use of forests is shifting in response to larger changes. It will be of interest to forestry practitioners, students, researchers, the private sector and civil-society organizations. The analysis of key global trends and outlook is particularly relevant to policy-makers and planners. The publication is available in Arabic, Chinese, English, French, Russian and Spanish.

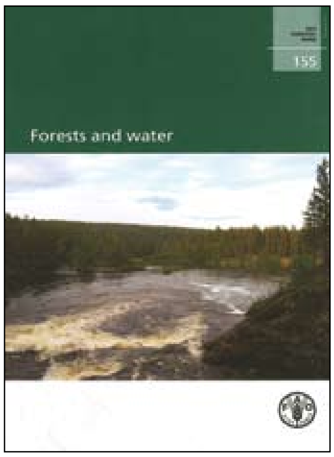
For further information and text downloads, see: www.fao.org/forestry/sofo

State of knowledge on forests and water

Forests and water. L.S. Hamilton, with contributions from N. Dudley, P. Greminger, N. Hassan, D. Lamb, S. Stolton & S. Tognetti. 2008. FAO Forestry Paper No. 155. Rome, FAO. ISBN 978-92-5-106090-2.

Forested catchments supply a high proportion of the water for domestic, agricultural, industrial and ecological needs in both upstream and downstream areas. A key challenge faced by land, forest and water managers is to maximize the benefits that forests provide without detriment to water resources and ecosystem function. There is an urgent need for a better understanding of the interface of forests and trees with water and for embedding this knowledge in policies.

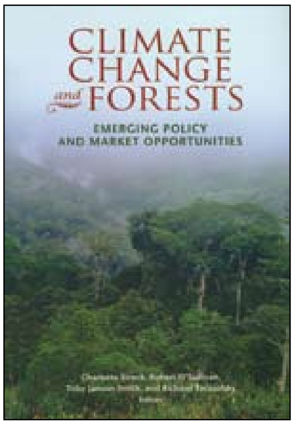
Forests and water, initiated in the context of the Global Forest Resources Assessment 2005, highlights the need for holistic management of complex watershed ecosystems, taking into account interactions among water, forest and other land uses as well as socio-economic factors. It also seeks to reverse some false or misleading generalizations about the impact of forest cover on downstream annual and seasonal flows. Until a few years ago, forest and water policies were based on the assumption that under any hydrological and ecological circumstances, forest is the best land cover for maximizing water yield, regulating seasonal flows



and ensuring high water quality. According to this assumption, conserving (or extending) forest cover in upstream watersheds was assumed always to be the most effective measure for enhancing water availability, as well as for preventing floods in downstream areas. The important role of upstream forest cover in ensuring the delivery of quality water has been confirmed, but in some situations, especially in arid or semi-arid ecosystems, forests may not be the best land cover for increasing downstream water yields.

This clear and informative publication explains the role of forests in the hydrological cycle and their influence on water quantity and quality. One chapter focuses on critical, "red flag" forest situations: mountain cloud or fog forests, swamp forests, forests on saline-susceptible soils, forests on steep sites with high landslip risk, riparian buffer zones, forests for municipal water supply, vernal pools and forests providing avalanche protection. Another chapter addresses the special case of mountainous small islands. Emerging systems of payment for watershed services are also addressed.

This state-of-knowledge publication will be of interest to a broad range of technical experts and scientists as well as policy- and decision-makers. *Forests and water* is also available online at: www.fao.org/forestry/publications



Climate change and forest opportunities

Climate change and forests: emerging policy and market opportunities. C. Streck, R. O'Sullivan, T. Janson-Smith & R. Tarasofsky, eds. 2008. London, UK, Chatham House & Washington, DC, USA, Brookings Institution Press. ISBN 978-0-8157-8192-9.

This up-to-date book provides an excellent overview of the legal, economic and environmental issues related to forests and climate change mitigation. It provides an overview of forest issues in the international climate change arena, addressing such issues as

Genetic improvement of forest plantation species in Australia and New Zealand

Australian Forestry, a journal issued by the Institute of Foresters of Australia (IFA), has over the past two years published a series of papers on experiences and achievements in the improvement of forest plantation species through the application of conventional and advanced tree improvement techniques.

The papers cover a number of native and introduced hardwood and softwood tree species planted in Australia and New Zealand by government institutions, private enterprise and smallholders for productive, protective and environmental uses. A number of the programmes described had already begun 60 years ago and these, together with more recent programmes, have generated a substantial amount of knowledge and expertise, resulting in innovative practices in plantation forestry and the improvement of traits such as growth and yield, stem form, wood properties, disease resistance and the ability to grow in conditions generally considered marginal or adverse to plant growth.

In addition to their scientific interest, the articles constitute excellent case studies which can potentially provide guidance and directions for programmes using the same or similar forest plantation species in other countries and regions of the world.

The full papers can be ordered through the IFA website (www.forestry.org.au) for 20 Australian dollars each (approximately US$15). Abstracts of the papers can be found at: www.forestry.org.au/ifa/c/c2-ifa.asp

Achievements in forest tree genetic improvement in Australia and New Zealand – papers published in *Australian Forestry*, 2007 and 2008

1. *Eucalyptus pilularis* Smith tree improvement in Australia. M. Henson & H.J. Smith. 70(1), 2007.
2. Development of *Corymbia* species and hybrids for plantations in Eastern Australia. D.J. Lee. 70(1), 2007.
3. Tree improvement of *Eucalyptus dunnii* Maiden. H.J. Smith, & M. Henson.70(1), 2007.
4. Tree improvement for low-rainfall farm forestry. C.E. Harwood, D.J. Bush, T. Butcher, R. Bird, M. Henson, R. Lott & S. Shaw. 70(1), 2007.
5. Genetic improvement of Douglas-fir in New Zealand. C.J.A. Shelbourne, C.B. Low, L.D. Gea & R.L. Knowles. 70(1), 2007.
6. Genetic improvement and conservation of *Araucaria cunninghamii* in Queensland. M.J. Dieters, D.G. Nikles, & M.G. Keys. 70(2), 2007.
7. Maritime pine and Brutian pine tree improvement programs in Western Australia. T.B. Butcher. 70(3), 2007.
8. Successful introduction and breeding of radiata pine in Australia. H.X. Wu, K.G. Eldridge, A.C. Matheson, M.P. Powell, T.A. McRae, T.B. Butcher & I.G. Johnson. 70(4), 2007.
9. Genetic improvement of *Eucalyptus nitens* in Australia. M. Hamilton, K. Joyce, D. Williams, G. Dutkowski & B. Potts. 71(2), 2008.
10. *Pinus radiata* in New Zealand. R.D. Burdon, M.J. Carson & C.J.A. Shelbourne. 71(4), 2008.

carbon trading and forestry projects under the Clean Development Mechanism. Avoided deforestation and voluntary carbon offsets are explored in depth. The remaining chapters provide description and analysis of the issues that shape the climate debate in the forest sector, including permanence, methodologies for measurement and monitoring, and legal issues. Eight case studies provide practical illustration.

More than 50 authors contributed the 21 chapters which address such topical issues as "How renewable is bioenergy?" and "Creating incentives for avoiding further deforestation: the nested approach".

This is not light reading; it is a book for people who have some knowledge of the subject and are interested in learning more about the policy issues related to forests and climate change. For readers looking for an in-depth review of the most debated forest policy issues of the last few years (and probably the next few as well), this book is highly recommended.

Climate change and Mediterranean forests

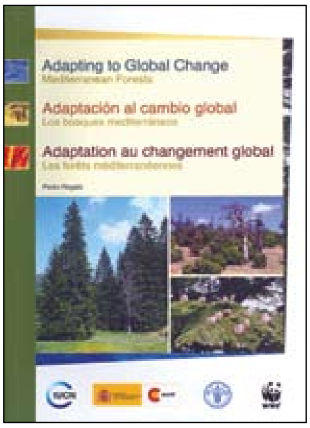
Adapting to global change: Mediterranean forests. 2008. Gland, Switzerland & Malaga, Spain, International Union for Conservation of Nature (IUCN).

Forests are among the most important ecosystems of the Mediterranean. They are rich in biodiversity and provide a variety of environmental services. But poor management, overexploitation, pollution, rapid and abrupt land-use changes resulting from economic development and international market pressures are provoking the degradation of Mediterranean forests. Climate change, bringing extreme weather events such as heat waves, torrential rainfall, drought and windstorms, further aggravates these factors.

This multilingual publication (in English, French and Spanish) gives a good picture of the current state of Mediterranean forests and covers global warming trends, lessons from past climate changes, current and forecasted climate change impacts and measures for adapting to climate change in the region. It proposes strategies for dealing with specific issues such as genetic resources conservation, landscape adaptation, capacity building and bolstering social resilience.

This book builds on discussions at the workshop Adaptation to Climate Change in Mediterranean Forest Conservation and Management, held by IUCN and the World Wide Fund for Nature (WWF) in Greece in April 2008. The statement of the participants, the Athens Statement on Adaptation to Climate Change in Mediterranean Forest Conservation and Management, is provided in an annex.

With editorial input provided by international organizations such as FAO and the United Nations Environment Programme (UNEP), governments, forest managers and users, research institutions and the private sector, *Adapting to global change* represents a first step for developing a joint programme of work and strategy on Mediterranean forest adaptation to climate change.



Using wood to mitigate climate change

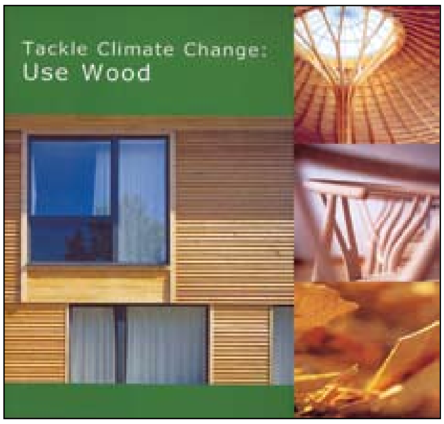
Tackle climate change: use wood. 2006. Brussels, Belgium, European Confederation of Woodworking Industries (CEI-Bois).

This beautifully illustrated publication lays out the environmental arguments for using wood as a means of mitigating the effects of climate change. It assesses the CO_2 impact of different materials and shows how much CO_2 can be saved by using wood. It reviews the eco-cycle of wood and wood-based products, with an emphasis on the environmental and socio-economic benefits of using wood in the European context. The context is established through background on Europe's forests and wood industry, supported with facts and figures.

The approach is pragmatic and forward thinking. CEI-Bois estimates that an annual 4 percent increase in Europe's wood consumption would sequester an additional 150 million tonnes of CO_2 per year and that the market value of this environmental service could equal about €1.8 billion a year.

The clearly written text is brought to life with over 60 colour photographs and easy to read graphs and tables. The back of the book includes definitions of terms and references to additional literature.

This high-quality product invites reading and is intended to



introduce a wide public to the environmental benefits of using wood. It will also be attractive to forest sector insiders looking for a concise and thorough overview.

Tackle climate change: use wood is also available online at: www.cei-bois.org

Verification issues in the timber trade

Legal timber: verification and governance in the forest sector. D. Brown, K. Schreckenberg, N. Bird, P. Cerutti, F. Del Gatto, C. Diaw, T. Fomété, C. Luttrell, G. Navarro, R. Oberndorf, H. Thiel & A. Wells. n.d. London, UK, Overseas Development Institute (ODI). ISBN 978-0-85003-889-7.

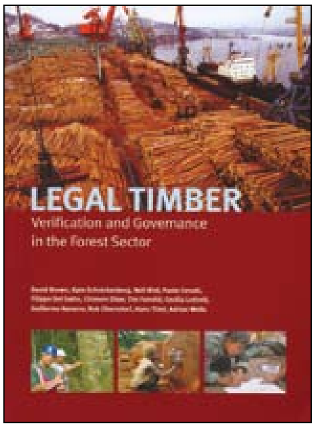
This book focuses on a topical issue in international forest policy: how to verify the legality of traded timber in ways that will satisfy both the commercial interest of producers and the social and environmental concerns of civil society and consumers. The issue is not just technical; verification raises questions involving the balance between the sovereign rights of producer States and the role of forests as vital public goods. Furthermore, these questions straddle national and international interests.

Legal timber is based on the findings of the VERIFOR project, an applied research collaboration involving partners in Europe, Africa, Latin America and Asia. After an introduction to the concept of verification and a review of how policy on illegal logging has evolved, the publication presents case studies of verification systems in a dozen countries: Brazil, Cambodia, Cameroon, Canada, Costa Rica, Ecuador, Ghana, Honduras, Indonesia, Malaysia, Nicaragua, and the Philippines.

The publication goes on to address issues such as ownership of verification systems, the legal basis for verification, independence, developmental impacts, the relation of certification and verification, and technologies and multistakeholder processes that can support improved forest governance. Finally, it proposes some principles for the design of effective forest verification systems.

The publication is the result of a collaborative effort between ODI and the Tropical Agricultural Research and Higher Education Center (CATIE), the Center for International Forestry Research (CIFOR) and the Regional Community Forestry Training Centre for Asia and the Pacific (RECOFTC).

While the subject matter is specific to the forest sector, the questions raised by this publication cast light on much wider questions of governance reform. It will be of interest to those working on forest governance and the management of extractive resources, trade certification and labeling, environmental policy and participatory development.



Commercial potential of non-wood forest products

Commercialization of non-timber forest products: factors influencing success – lessons learned from Mexico and Bolivia and policy implications for decision-makers. E. Marshall, K. Schreckenberg & A.C. Newton. 2006. United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). ISBN 92-807-2677-3.

Non-wood forest products (NWFPs), including nuts, resins, fruits, oils and spices, are an important source of nutrition and income to many of the world's communities. This book, based on experiences in Mexico and Bolivia, looks at the process of commercialization of NWFPs. It examines market access, value chains and whether commercialization will contribute to sustainable forest management.

The book begins by explaining how qualitative and quantitative data were collected and integrated in the analysis.

The authors believe that NWFPs can be more than a safety net. They analyse how these products can improve income and living standards, offering a framework for commercialization. Suggestions are given for managing transaction costs, working with non-governmental organizations (NGOs) and conducting environmental impact assessments.

Produced through collaborative efforts by the Overseas Development Institute, UNEP-WCMC, Bournemouth University and partners in Mexico and Bolivia, *Commercialization of non-timber forest products: factors influencing success* assesses the viability, sustainability and poverty alleviation potential of commercialization projects and offers support tools for effective decision-making by NGOs and other actors.