6 Management for Adaptation

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Abstract: This chapter develops a framework to explore examples of adaptation options that could be used to ensure that the ecosystem services provided by forests are maintained under future climates. The services are divided into broad areas within which managers can identify specific management goals for individual forests or landscapes. Adaptation options exist for the major forest regions of the world but the scientific basis for these adaptation options and their potential effectiveness varies across regions. Because of the great variation in local conditions, no recommendations can be made that are applicable to an entire domain. The choice of management option will depend on the likely changes occurring in the forest, the management objectives of that forest, its past management history and a range of other factors. Local managers must have sufficient flexibility to choose the most appropriate suite of management options for their conditions. The current failure to implement fully the multi-faceted components of sustainable forest management is likely to limit the ability of forest management to adapt to climate change. Forest managers will need to plan at multiple spatial and temporal scales and will need to adopt adaptive collaborative management as their primary form of management. Careful monitoring and evaluation will be required, with a change in focus from outputs to outcomes.

Keywords: climate change, forest management, forest planning, adaptation, boreal forests, temperate forests, subtropical forests, tropical forests, deforestation, forest degradation, carbon emissions, carbon sinks

6.1 Introduction

Forest management has a long history of development through scientific research and through management experience. Management theory and practice continue to evolve as new stresses and threats affect forest dynamics. In this chapter, we identify a number of services associated with sustainable forest management. The provision of these services, as a whole, comprises sustainable forest management (SFM). However, SFM is more a concept than a practice – it represents a target which many managers aspire to, but which few if any have achieved. This does not preclude SFM as an objective: the idea of continuous improvement is one that is common in management, and as applicable in forestry as in any other sector.

How might climate change affect the ecosystem services provided by forests, both directly and indirectly? There are many different possibilities, with some changes (such as changes in the frequency and severity of forest disturbances) affecting multiple services. In relation to the thematic areas of sustainable forest management developed by the United Nations Forum on Forests (UNFF 2004), it is possible to identify a number of broad groups of impacts:

Forest cover: conversion of forests to non-woody energy plantations; accelerated deforestation and forest degradation; increased use of wood for domestic energy.

Biodiversity: alteration of plant and animal distributions; loss of biodiversity; habitat invasions by non-native species; alteration of pollination systems; changes in plant dispersal and regeneration.

Productivity: changes in forest growth and ecosystem biomass; changes in species/site relations; changes in ecosystem nitrogen dynamics.

Health: increased mortality due to climate stresses; decreased health and vitality of forest ecosystems due to the cumulative impacts of multiple stressors; deteriorating health of forest-dependent peoples.

Soils and water: changes in the seasonality and intensity of precipitation, altering the flow regimes of streams; changes in the salinity of coastal forest ecosystems; increased probability of severe droughts; increased terrain instability and soil erosion due to increased precipitation and melting of permafrost; more/earlier snow melt resulting in changes in the timing of peak flow and volume in streams.

Carbon cycles: alteration of forest sinks and increased CO_2 emissions from forested ecosystems due to changes in forest growth and productivity.

Tangible benefits of forests for people: changes in tree cover; changes in socio-economic resilience; changes in availability of specific forest products (timber, non-timber wood products and fuelwood, wild foods, medicines, and other non-wood forest products).

Intangible services provided by forests: changes in the incidence of conflicts between humans and wildlife; changes in the livelihoods of forest-dependent peoples (also a tangible benefit); changes in socio-economic resilience; changes in the cultural, religious and spiritual values associated with particular forests.

From the above, it is evident that one particular impact could be affecting a number of the thematic areas – changes in the magnitude and frequency of forest disturbances will affect all the ecosystem services provided by forests. Consequently, many adaptation options focus on reducing the potential impact of major disturbances. It is important to emphasize here that we specify no direction in the potential changes. For example, in some areas, the magnitude and/or frequency of disturbances may actually decrease. However, under all climate scenario clusters (see Chapter 3), the magnitude and frequency of forest disturbances are predicted to increase in one or more parts of the world.

Numerous possibilities exist to meet the challenges presented above. In forest management, these include both reducing the effects of potential impacts and developing new management practices and strategies to take advantage of new opportunities under a changing climate. These adjustments will also involve taking into account the perceptions of climate risk by the various stakeholders or 'actors' of change (individuals, communities, governments, private institutions and organizations) (Adger et al. 2007). The adjustments will be influenced by the adaptive capacity of the forest ecosystem, and by the socio-economic communities and the political setting of the forest. An example, drawn from the tropical rainforests of Latin America, is provided in Box 6.1.

6.2 Adaptation and Adaptive Management

Many of the actions that a manager might take to help forests and forest-dependent communities adapt to climate change involve substantial amounts of uncertainty. Adaptive management provides a mechanism to move forward when faced with such uncertainty. In general, adaptive management can be viewed as a systematic process for continually improving management policies and practices by monitoring and then learning from the outcomes of operational programmes. Within the context of climate change, forest management aims at moderating or offsetting the potential damage or taking advantages of opportunities created by a given climate change. In this context, adaptive forest management is one tool that could enable managers to adjust the structure and the consequent functioning of the forest ecosystem to resist harmful impacts of climate change, and to utilize the opportunities created by climate change.

Adaptive management involves a process of observation, analysis, planning, action, monitoring, reflection and new action (Figure 6.1). A key part of the process is to ensure that there is adequate monitoring of the effectiveness of management actions: are they

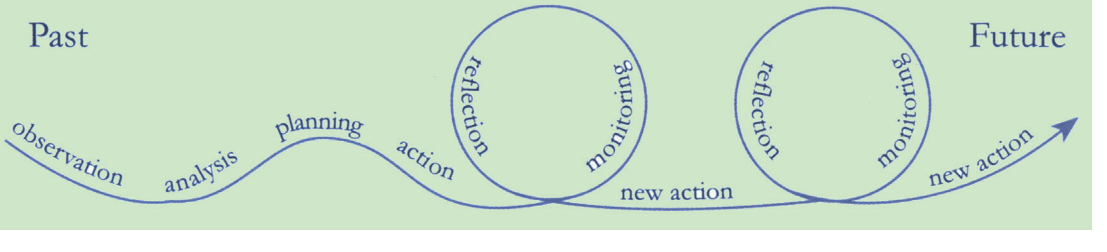

Figure 6.1 Framework for Adaptive Management (Colfer 2005a).

Box 6.1 Community forest management as an option for adaptation of forest-dependent people in the tropical rainforests of Latin America

The natural forests of the tropics store as much carbon in vegetation and soil as the temperate and boreal forests combined (Field et al. 1998, Fischlin et al. 2007). However, in the tropical forests, sustainable forest management is the exception rather than rule (e.g. FAO 2007). Millions of hectares of tropical rain forest disappear every year (FAO 2007), and an unknown, possibly even greater area of forests is degraded in different degrees by unplanned timber and non-timber harvesting activities. A number of options aimed at reducing the risk of forest loss are proposed in Appendix 6.1. Governments have implemented many of them in one way or another in the recent past without much success; deforestation continues. This does not make the presented options less valid. Rather, in order to be more successful in the future, it is necessary to analyse why in some cases the proposed actions have been implemented with more success than in others.

Between 2005 and 2007, about 20 forest-related scientists working in Latin America did such an analysis about community forest management (CFM), one of the options also proposed in Appendix 6.1: 'Enhance local welfare through the promotion of community-based forest management and restoration, the development of agroforestry, the availability of microfinance, training in non-wood forest product (NWFP) management, manufacturing and marketing, and a greater role for women.' The scientists concluded that after twenty years of support to community forest management, and over 200 million hectares of forest land conceded to indigenous people in Latin America (Sunderlin et al. 2008), a number of promising examples exist (Sabogal et al. 2008). From the literature search and their own experiences in CFM, they considered that some of the main factors that contributed to the success of these examples were:

- CFM differs according to the natural and cultural settings of each community and therefore may require local solutions. Institutional support should allow for such adaptations rather than focus on the requirements of CFM under 'average' conditions.
- Development of an integrated approach towards CFM, combining local knowledge with science-based knowledge and allowing the communities to develop according to their own priorities. This may require supporting agencies to adapt their own objectives, working methods and time-spans to those of the local communities.
- Many techniques and methods used to promote CFM have been designed for industrial settings (e.g. forest inventories, mechanized harvesting). Communities that were able to adapt these to their own needs (e.g. multi-product forest inventories) and capacities have been more successful in the continued implementation of CFM.
- Different approaches to entrepreneurial community level organizations (community companies, alliances, productive arms of political organizations) have helped the insertion of communities into market economies. These need to be analysed on a case-by-case basis.
- Local people were able to strengthen their skills and become more involved in CFM where community forest organizations have been able to build on the existing skills and regulations that govern social relations and natural resource use.
- Existing external institutions (political framework, markets) that facilitate the insertion of small producers and indigenous people (e.g. Fair Trade labels) may need to be adjusted (Sabogal et al. 2008).

These experiences suggest that for many Latin-American forests the successful application of the adaptation options proposed in this report will also require an analysis of the best way to apply them. Although many suggestions call for small adjustments in existing SFM practices, an in-depth analysis of SFM and the needs and skills of its different potential practitioners is needed to extend the forest area under SFM, in particular in forest areas assigned to (indigenous) communities.

achieving the desired results and have there been any unintended or underestimated consequences?

The terms adaptation and adaptive management are often incorrectly used interchangeably. The former involves making adjustments in response to or in anticipation of climate change and there are a wide variety of adaptation options that a forest manager may consider (see Appendices 6.1 to 6.9) whereas the latter describes a management system that may be considered, in itself, to be an adaptation tactic

(Ogden and Innes 2007). True adaptive management rigorously combines management, research, monitoring and the means of changing practices so that credible information is gained and management activities can be modified by experience; it is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programmes (BCMOF 2006a). Its most effective form – 'active' adaptive management – employs management programmes that are designed experimentally to compare selected policies or practices, by evaluating alternative hypotheses about the system being managed (BCMOF 2006a). Adaptive management involves recognizing uncertainty and establishing methodologies to test hypotheses concerning those uncertainties; it uses management as a tool not only to change the system but to learn about the system (Holling 1978, Lee 1993, 2001).

The concept of adaptive management has, for many ecologists, become a foundation of effective environmental management for initiatives characterized by high levels of ecological uncertainty (Gregory et al. 2006). However, many of the initiatives promoted as examples of adaptive management appear to lack essential characteristics of the approach. Gregory et al. (2006) proposed explicit criteria to assist forest managers to determine the appropriateness of either passive or active adaptive-management strategies as a response to dealing with uncertainty in decision-making. They suggest four criteria – dealing with spatial and temporal scale, dimensions of uncertainty, the evaluation of costs and benefits, and institutional and stakeholder support – and apply these criteria to four case-studies with different management contexts and with an expressed desire to adhere to adaptive management principles. In doing so, they showed that adaptive management may be more appropriately applied in some contexts than in others.

This reflects the realization that adaptive management goes beyond the focus on scientific method, statistical design and analytical rigour favoured by its early proponents (e.g. Walters 1986). Instead, there is now an expectation of much greater stakeholder involvement in adaptive management, such that the entire concept has been renamed adaptive collaborative management (Colfer 2005b, Diaw and Kusumanto 2005) or adaptive co-management (Armitage et al. 2007). To be effective, there will need to be much greater cooperation between stakeholders, more flexibility for management actions, a social license for action in the absence of conclusive evidence or understanding, and effective ways for including what scientific expertise there is in political and social processes that inform, educate and modify policy (Stankey 2009).

Climate change poses other challenges to the effective application of active adaptive management experiments. The long time frames required to gather information from experiments may not match the time frames required for decision-making, and may exceed the professional lifetimes of several generations of managers. In addition, when results do become available from lengthy experiments on topics such as tree species establishment, growth and survival, they may no longer be relevant as the climate continues to change. It is important to recognize that many of the issues facing adaptive management may have less to do with the approach itself than with the indiscriminate choice of contexts within which it is now applied (Gregory et al. 2006). Applying adaptive management principles as an approach to SFM is not simple. It requires effort at many levels and ongoing commitment in order to be effective.

While the adaptive-management cycle has been widely cited in forestry as a means to deal with the uncertain outcomes arising from management actions, it is important to recognize that there are other knowledge systems (e.g. local knowledge) and that these could also be used to deal with the uncertainties associated with climate change. Managers often discount such alternative management systems, mainly because they have been trained in 'scientific' approaches to forest management. However, the alternative management systems are increasingly recognized as being important and containing invaluable local information relevant to management.

The need for adaptation within forest management varies across ecosystems and tenure types and is related to the vulnerability of forests to climate change as well as to the vulnerability of forest-dependent people to changes in the provision of ecosystem goods and services. The United Nations Development Programme – Global Environment Facility has developed an Adaptation Policy Framework (APF) that provides an approach that permits users to clarify their own priority issues and to implement adaptation strategies, policies and measures (Lim and Spanger-Siegfried 2005).

The APF has four basic principles. Lim and Spanger-Siegfried (2005) list these as:

- Adaptation to short-term climate variability and extreme events is included as a basis for reducing vulnerability to longer-term climate change.
- Adaptation policy and measures are assessed in the context of development.
- Adaptation occurs at different levels in society, including the local level.
- Both the strategy and the process by which adaptation is implemented are equally important.

A key feature of the APF is flexibility, and this is directly applicable to the adaptation of forest management in response to climate change. There is no 'one size fits all' solution, and there is also recognition that the sustainable management of ecosystems is not only extremely complex (Harris 2007), but that ecosystems that we classify as similar (e.g. tropical forests) in reality may respond very differently to external stresses (cf. Savory and Butterfield 1999). Managers must be given the flexibility to respond in ways that meet their particular needs, and only those options that are applicable to the local situation should be adopted (Lim and Spanger-Siegfried 2005). For example, a manager working with tropical forest plantations may only need to consider an 8–20-year time-span (the length of a rotation), while a manager dealing with semi-natural forest in the boreal domain may have to consider a 120-year time-span.

Managers adopting the APF can follow a clear pathway that involves several steps. These are (Lim and Spanger-Siegfried 2005):

1. scoping and designing the management
2. assessing current vulnerability
3. assessing future climate risks
4. formulating an adaptation strategy
5. continuing the adaptation process.

The pathway assumes a linear development, and may be disrupted by the impacts of extreme events. An important aspect of this approach is the final step. Both the climate and forest ecosystems are constantly changing, and managers will need to adapt their strategies as the climate evolves over the long term. An option that might be appropriate today given expected changes over the next 20 years may no longer be appropriate in 20 years' time. This will require a continuous programme of actions, monitoring and evaluation – the adaptive management approach described above.

6.3 Management Options for Maintaining and Providing Forest Ecosystem Services

6.3.1 Introduction

A key argument made in this report is that forest management actions taken to adapt to climate change can be consistent with actions taken to manage forests in a more sustainable fashion. This argument has been made on a number of occasions (e.g. ITTO 2008), and has recently been put forward in relation to climate change mitigation (Putz et al. 2008b). The potential for a win-win situation exists for forest stakeholders: whichever scenario of climate change turns out to be closest to reality, actions will have been taken that will be of long-term benefit to the forest. Similarly, many management actions taken in the context of adaptation, such as the establishment of shade trees in urban areas or the prevention of large-scale forest fires, could also assist in the mitigation of climate change (Ravindranath 2007). To be effective in mitigation, forests will have to adapt to climate change. Ensuring that they are will bring benefits not only to the forests and to climate-mitigation efforts, but will have additional benefits associated with poverty reduction and the preservation of ecosystem services (Eliasch 2008).

Throughout this report, a number of trends are apparent. Firstly, as described in Chapter 3, there are many possible ways that the climate could develop: the likely climatic futures suggested by the IPCC are based on the analysis of many possible scenarios of human development over the next 100 years. In addition, the General Circulation Models currently used to examine the possible future climate associated with any given scenario differ in their outputs, particularly as the scale is decreased (from continental to regional to local)(Chapter 3). Secondly, there are many possible impacts of climate change on forests, but these will differ according to location, past history, vegetation type, management activities and a range of other factors.

A forest manager considering taking action to promote the adaptation of a forest to climate change is faced with a range of choices. Some of the potential actions may actually counteract one another – balancing the consequences of management actions is a critical part of modern forest management (Buongiorno and Gilless 2003, Kangas et al. 2008, Bettinger et al. 2009). Many actions that a manager is likely to take will be based on past experience. There is often a basic assumption that any changes caused by climate will be similar in impact to those caused by other factors, but this is unlikely to be true. Climate change may result in the development of new forest ecosystems not previously encountered, will change site/species relationships, will alter the relative growth rates of different species and provenances within species and will cause a range of other changes. In addition, human activities may mitigate or accelerate the effects of climate change (cf. Laurance and Peres 2006), and the forest manager needs to be able to recognize these interactions and, through negotiation with other stakeholders, prevent their negative impacts and promote their positive effects. Human-induced fires, for example, contribute to the vicious circle of forest degradation, climate warming, drier areas and increased fire hazard (Nepstad 2007, Betts et al. 2008a, Aragão et al. 2008).

Sub-chapters 6.3 to 6.6 of this report are based on the assumption that appropriate management can be used to sustain forest ecosystem services. This is not necessarily happening: the International Tropical Timber Organization (ITTO 2006) reports that only

4.5% of the 814 million ha of natural forest in the permanent forest estate of its producer member countries is managed truly sustainably, although there are plans in countries such as Brazil (e.g. Verissimo et al. 2002, Schulze et al. 2008) to increase the area of forest managed using sustainability criteria. Elsewhere, while there are many claims that forests are being managed sustainably, the majority of management units fulfil only a proportion of the requirements of true sustainable forest management. This is partly because it is possible to cover all the requirements of sustainable forest management at the scale of a large forest or region, whereas many management units are smaller than this, and most management is still focused at the scale of the tree and stand. This situation suggests that adaptation options depending upon additional forest management will be increasingly difficult to implement unless the social factors that influence current management (or lack of management) are addressed.

Over the past 20 years, the forest sector has reached broad agreement on the criteria that determine sustainable forest management. Forests are now considered to be social-ecological systems that involve both nature and society. The management of the societal impacts of altered forests and the actions of society on altered forests are just as important as the management of the biological systems, without taking into account societal linkages. Sustainable forest management is today as much about the people who inhabit, work in or utilize forests as it is about the forest ecosystems themselves, and this changed emphasis is likely to continue into the future. Such changes have been expressed in the four types of services described in the Millennium Ecosystem Assessment (MEA) and introduced in Chapter 1 and expanded upon in Chapter 3, namely supporting, provisioning, regulating and cultural services.

In the following sections, management responses to potential impacts of climate change on the ecosystem services provided by forests are examined. The MEA services classification has been further divided into the thematic elements of sustainable forest management, based on those agreed by the United Nations Forum on Forests (UNFF 2004), since these may be more familiar to many forest managers. Each section is linked to a table providing examples of potential adaptation options. The tables, provided in the Appendices, are not intended to be prescriptive. Rather they present a series of possibilities that managers might like to consider. It will not be possible to utilize every option at every site, as the choice of option will depend on the management objectives of the forest, the nature of the forest and the likely change in climate. Some of the options are incompatible with others, and managers will need to adopt some of the more sophisticated planning techniques and decision analysis tools that are available today to work out which options will generate the desired outcomes. A description of these tools is outside the scope of this report. In addition, managers need to decide how proactive they wish to be: are they trying to facilitate ecosystem adaptation or engineer resistance through proactive management strategies (Joyce et al. 2008)? As indicated in the following chapter, forest policies need to allow sufficient flexibility to enable managers to utilize the range of options that are available to them (Bodin and Wiman 2007).

Planning for sustainable forest management occurs at three levels: strategic, tactical and operational (Bettinger et al. 2009). Strategic plans provide direction on how the mix of forest resources will be managed in a given area and are concerned with larger areas and longer time frames. They often describe desired future forest conditions and indicate broad strategies for how these conditions will be achieved, such as landscape zoning. Tactical plans are shorter term than strategic plans, and focus on how a strategic plan will be implemented. Operational plans are developed to be consistent with the objectives established in the strategic plans and are developed for smaller areas and shorter time frames (often less than a year). They provide detailed descriptions how activities will be undertaken. In practice, one or more of the planning levels may be merged with another in order to save time and costs. Consistency between the different levels of planning has been found in practice to be essential; strategic plans play an important role in determining the appropriate choice of forestry practices described in operational plans, and tactical plans describe how the objectives identified in strategic plans are to be implemented. Because of the differences in strategic, tactical and operational planning, it is important to distinguish at which planning level adaptation options are most appropriately considered (Ogden and Innes 2007a). In the long term, and in the light of eventual climate impacts, the implementation of climate-change adaptation options in both strategic and operational plans will be necessary to realize sustainable forest management. In the tables presented in the appendices, potential management actions have been divided into strategic and operational actions, reflecting whether an action lies closer to either end of the management spectrum.

An important element of any adaptation strategy will be to ensure that adequate monitoring is undertaken. The monitoring needs to be capable of documenting changes in forest species, processes and ecosystems, and should also be capable of enabling the evaluation of the effectiveness of adaptation strategies. This is a critical part of the adaptive management described in the previous section. To date, the forest community has been slow to establish monitoring schemes to achieve these aims, relying instead on adapting existing monitoring. While this may be appropriate for some situations, an important point is that new indicators and sampling designs will be required to monitor the impacts of climate change on forests properly.

6.3.2 Forest Management Strategies to Maintain the Extent of Forests

This is the first of the thematic areas of SFM developed by the United Nations Forum for Forests (UNFF 2004). Essentially, there is a desire to ensure that the global area of forests is maintained. This reflects the global concerns about the current loss of forests, particularly in tropical and subtropical regions (FAO 2007), and the impacts of these losses on global climate (Houghton 2003, Hassan et al. 2005, Fischlin et al. 2007). Such concerns have prompted calls to help mitigate the effects of climate change by reducing emissions of greenhouse gases from deforestation and forest degradation (e.g. Stern 2006, Eliasch 2008). It is difficult to say how forest area will be affected by climate change: for example, there is much speculation about the rate of pole-ward expansion of forests associated with climate change. While the distributions of many temperate and boreal tree species appear to be controlled primarily by energy constraints associated with different life-history strategies (Morin and Chuine 2006), the range of factors affecting forest dynamics in the arctic make such predictions very difficult (cf. Gamache and Payette 2005). Similarly, the future dynamics of the grassland–woodland ecotone in subtropical and tropical regions remains difficult to predict because of the many different factors that influence it (see Box 6.2). The number of tree species in tropical forests makes predictions of the responses of closed tropical forests to climate change difficult, especially given the challenges facing the collection of information on the ecophysiology of tropical tree species (cf. Mulkey et al. 1996, Turner 2001, Chambers and Silver 2004, 2005).

At a regional scale, it is unlikely that the present extent of current forests types will be maintained. In some places forest area will decrease as the environmental conditions become unsuitable for trees. In areas where moisture availability becomes a controlling factor, closed forest will change to open forest and savannah. In other areas, forest area will expand, either as a direct result of climate change (e.g. at the current northern and southern limits of forests) or as a result of afforestation policies (e.g. China, Cuba, Iceland, Vietnam). Within this context, the use of plantation species better adapted to future climate conditions than existing native species is an adaptation option. However, in addition to forest area, the many other factors that modern forest management involves need to be taken into account. For example, replacement of non-forest vegetation types with exotic plantations can be controversial (e.g. Myklestad and Saetersdal 2005, Buscardo et al. 2008), although impacts can mitigated (cf. Candan et al. 2006) and plantation forests can provide more habitat for native species than grazing land (Brockerhoff et al. 2008b). Alteration of groundwater levels caused by new plantations is also a controversial issue (Scott 2005, van Dijk and Keenan 2007; see also sub-chapter 6.5.1).

The cumulative impact of deforestation and forest degradation on the global extent of forests is a major concern, but primarily an issue associated with the mitigation of climate change. It is here that appropriate policies will have the greatest impacts on the processes affecting climate change. To a certain extent, this is addressed elsewhere in this chapter under the themes of biological diversity, water resources, multiple socio-economic benefits and contributions to global carbon cycles. However, there are possible options specifically aimed at maintaining forest cover: examples are detailed in Appendix 6.1.

With the global demand for wood continuing to increase, and the area of natural forest available for harvesting continuing to decline, increasing emphasis is being placed on high-yield plantations. In 2000, 35% of the global roundwood supply and 8% of fuelwood was derived from plantation forests (Sampson et al. 2005). In New Zealand, wood from plantations has entirely replaced the logging of natural forests and although vigorously resisted, a similar trend is occurring in Australia. Such plantations usually have much lower levels of genetic, species and ecosystem diversity than natural forests (Barlow et al. 2007a, 2007b), but may still have some value for biodiversity (Brockerhoff et al. 2008). The use of plantations to supply an increasing amount of wood or other products can reduce the continued long-term loss of biodiversity by avoiding deforestation and forest degradation in other areas, provided that the establishment of plantations is not preceded by the clearing of natural forests.

Attempts are being made in some parts of the world (especially central and northern Europe and western North America) to convert plantations to more natural forms of forest. While this may be at the cost of timber productivity, other ecosystem services provided by forests may benefit. An alternative strategy is to develop zones across the forest management unit, with areas reserved for conservation, areas with extensive forestry (which to a certain extent attempts to mimic natural forest ecosystems) and areas with intensive production where the primary focus is on timber productivity (Nitschke and Innes 2005, 2008). Such an approach is frequently referred to as TRIAD management (Hunter 1990, Thompson and Welsh 1993, Hunter and Calhoun 1996). Climate change

John Innes

Photo 6.1 Dead white spruce (*Picea glaucens*), Kluane, Yukon Territory, Canada. The spruce have been killed by the Spruce Beetle (*Dendroctonus rufipennis*), a species that is normally limited by cold winter temperatures. A series of warmer-than-average winters have allowed populations to develop, resulting in the mortality of almost 400 000 ha of this boreal forest.

is likely to influence the nature and success of such conversions since current planning is based on a status quo, instead of considering forest development under climate change.

The current emphasis on alternative fuels such as bioethanol is generating pressure for the creation of biomass plantations in areas currently without forest or with degraded, secondary or even primary forest and for the conversion of some forests managed for multiple purposes to forests managed for biomass production. There are many potential implications of this, ranging from loss of biodiversity (e.g. Robertson and van Schaik 2001, Aratrakorn et al. 2006, Chey VunKhen 2006, Peh et al. 2006,) to impacts on local communities (e.g. Sandker et al. 2007). Conversion of primary forest to oil palm plantations may actually result in net carbon emissions (Reijnders and Huijbregts 2008). However, there are also examples of positive impacts associated with such plantations, and any development needs to be considered within its relevant context.

6.3.3 Forest Management Strategies to Facilitate Natural Adaptation of Biological Diversity

Forest biodiversity is essential to support the ecosystem services provided by forests and to maintain the adaptive capacity of forests to climate change (Noss 2001, Drever et al. 2006). Forest managers have various tools and options to manage forests for a continuous supply of these services, at various scales from large regional scales to forests stands. The effects of climate change will alter forests in many ways, will change the local biodiversity and will result in a change in many of the services available from forests in given areas (Hannah et al. 2002, Malhi and Phillips 2005, IPCC 2007, Millar et al. 2007). Effects will include altered forest ecosystems (species composition and structure), altered processes (increased fire, increased insect attack, extreme events leading to gaps, and altered productivity) and altered physical habitats (changes in forest microclimates) (McCarthy 2001, Parmesan and Yohe 2003, Lewis et al. 2004, 2006, Pounds et al. 2006, Millar et al. 2007, Joyce et al. 2008). Some of these changes may result in the extinction of species, particularly in some specific areas, such as mountains in tropical areas (e.g. Williams et al. 2003, Pounds and Puschendorf 2004, Andreone et al. 2005, Pounds et al. 2006, Rohan et al. 2007, Laurance 2008). Forest managers can adapt to many of these changes by changing their management regimes and activities; at a minimum, they can 'hedge their bets' with respect to climate change and, at best, respond to climate change by managing forests at multiple scales to reduce the long-term effects of climate change on the services that they expect from their forests (e.g. Millar et al. 2007). Work should be directed towards determining the best actions for resisting change, enabling systems to respond to and recover from change, and facilitating the inevitable changes in forest systems (Millar et al. 2007). The avoidance of undesirable impacts on biodiversity is a key aspect of sustainable forest management (see, for example, Hawksworth and Bull (2006). Conversely, many forestry activities are specifically intended to maintain or increase biodiversity (e.g. Hunter 1999, Lindenmayer and Franklin 2002, Newton 2007). A number of options are listed in Appendix 6.2.

A range of management actions may be taken to assist biodiversity adaptation to climate change (e.g. Hannah et al. 2002, Biringer et al. 2005, Lamb et al. 2005, Carnus et al. 2006, Brockerhoff et al. 2008, Killeen and Solórsano 2008). Such activities represent a major potential role for forest managers in the future. In taking any action, forest managers need to consider what the forest composition might be under different scenarios of climate change, since major changes are likely in some areas (e.g. Betts et al. 2008b, Iverson et al. 2008, Phillips et al. 2008). Any management action should be designed to increase the forest's ability to achieve this new composition through an understanding of natural processes (Hannah et al. 2002). This is particularly important given that under some scenarios of climate change some species may be unable to adapt sufficiently quickly without assistance (e.g. Savolainen et al. 2007, Aitken et al. 2008), with closed forests in some areas being replaced by woodland, scrub or grassland (e.g. Barlow and Peres 2008, Betts et al. 2008b).

Over broad regions, forest management could employ landscape-level strategies to conserve biodiversity (Brockerhoff et al. 2008) by enabling natural migration of species to areas with more suitable climates, the so-called 'new climate space' (Pearson et al. 2002). Such strategies would include reducing fragmentation and maintaining connectedness, especially between various protected areas. This is a complex issue, as not only are geographic corridors necessary, but it is also important to ensure that corridors providing different stages of forest development are present. This is because some species need particular stages of forest development for their survival, as has been shown for saproxylic insect assemblages in boreal forests (e.g. Cobb et al. 2007, Jacobs et al. 2007, Spence et al. 2008).

Managers might reduce anticipated effects of increased fire on biodiversity by developing species mixes across landscapes that reduce the spread of fires (Hirsch 2001) and by enhancing fire-fighting capacity. At a stand level, managers could protect isolated populations of species at the northern edges of their ranges and enhance their capacity for successful reproduction. Assisted migration of provenances and species might be used to enable forest types to adapt to climate changes (Millar et al. 2007). The goal of such strategies would be to reduce the effects of climate change on the services provided by forests.

In some cases, conditions may become unsuitable for forests at a given location. The relationship between grassland, woodland and closed forest may change, with the future vegetation type being determined by the particularities of the climate and soil and by management activities such as fire and grazing (Dubbin et al. 2006, Umbanhowar et al. 2006, Rull 2007). There is experience in the ecology and management of such ecosystems (and changes between them), particularly in Australia (McIntyre et al. 2002, Lindenmayer et al. 2005, Banfai et al. 2007, Kirkpatrick and Bridle 2007), but also in the savanna landscapes of other subtropical and temperate domains (e.g. Augustine et al. 2003, Savadogo et al. 2007, Oluwole et al. 2008, Scott et al. 2008). One of the biggest difficulties for forest managers will be associated with changes in land use as the vegetation changes. For example, as the canopy opens or fires become more frequent, grass species can increase in abundance, making the land attractive for livestock grazing, with subsequent implications for tree regeneration (e.g. Prober et al. 2007, Spooner and Biggs 2008).

Over the long term, managers will also have to recognize that an altered set of services may be produced and adapt management programmes accordingly. Similarly, in areas where there is a high probability that forests will be lost in favour of other ecosystems, such as grasslands, managers should recognize early on that their efforts and resources may best be focused elsewhere. The strategies employed will depend on the expected rate and scale of change, the capacity of the managers to initiate measures, the political will to act on recommendations for adaptation and the ability to shift the geographic location of the economic activities, although in many situations, such a shift may be impossible. Capacity is particularly important, as many small-scale landholders will have insufficient capacity to initiate the types of changes that may be necessary (Brondizio and Moran 2008, Guariguata et al. 2008).

The actual rate of change in forested ecosystems, and the rate of change in the distribution of individual species, is uncertain (Malcolm et al. 2002) but forests are long-lived and may show gradual responses (Millar et al. 2007). Projections for the spread of species with climate change are based on estimates derived from the early Holocene period, when a period of warming following the last glacial period was accompanied by the pole-ward spread of many species (e.g. Malcolm et al. 2002), or, as in the Amazon region, replacement of biomes in some ecotonal areas (Mayle and Power 2008). However, conditions today are very different largely owing to past human activities and it is uncertain whether the use of historic rates is appropriate (e.g. IPCC 2007). In practice, knowledge of the dispersal abilities of most tree species is very poor, particularly the conditions determining long-distance dispersal (Clark 1998, Clark et al. 1998, 1999, Kutter and Gratzer 2006). It may be necessary to assist certain species to move in response to changing conditions, for example, by moving seeds to more suitable locations or by even storing seeds ex situ until conditions stabilize.

The maintenance or creation of corridors may be an important strategy to help the movement of forest-dependent species to areas with more suitable climate conditions (Williams et al. 2005, Chapin et al. 2007, Mayle et al. 2007). However, this is likely to be particularly important for populations that are already small and isolated, such as the giant panda in the subtropical forests of south-west China (Yin et al. 2006). Several different types of corridor may need to be envisaged, including those that connect habitats at different heights above sea level and those that help maintain current biological diversity by providing functional connectivity between forest patches. However, evidence supporting the effectiveness of such corridors is limited (e.g. Beier and Noss 1998), and the speed of the current change in climate may be too great for the distribution of species to adjust, either with or without such corridors.

An important strategy in any long-term management plan to adapt to climate change is to include the use of reserves in enabling systems to adapt naturally to climate change in the absence of active management, and in increasing landscape connectivity (Noss 2001, Vos et al. 2008). Because of the uncertainty of its long-term effects, climate change presents some significant challenges for the location and design of forest reserves. Nevertheless, there has been too little recognition of the extent of this issue (Scott and Lemieux 2007), leading to protected area policies and a distribution of protected areas that are unrelated to projected climate change. In other areas conservation strategy recommendations may give much consideration to future climate change projections based on one or a few models (e.g. Killeen and Solórzano 2008) without considering information on adaptations in response to past climate changes (e.g. Mayle and Power 2008) or the impact projections of other models.

A common theme in this report is the high level of uncertainty about the precise long-term effects of climate change (Kirilenko and Sedjo 2007). However, in the long term, forests will benefit from adaptation actions at multiple scales to conserve biological diversity, even if the ecosystems that develop differ markedly from current forests (e.g. Hannah et al. 2002). It is important to recognize that climate change has strong potential to affect biodiversity negatively. Adaptation should thus aim at taking appropriate actions to attempt to conserve, as well as possible, existing forest biodiversity in areas with suitable conditions and at managing change as efficiently as possible to improve future forest conditions (Noss 2001, Millar et al. 2007).

6.3.4 Forest Management Strategies to Maintain Forest Health

There is considerable evidence that climate change will affect the health and vitality of forests. These effects may be subtle and long term, such as the spread of some pathogens, medium-term events such as droughts and insect epidemics, or they may be sudden and catastrophic, such as the occurrence of extreme storms and fires. Forest management can aim to reduce the impact of such events, but the events themselves may provide the opportunity for adaptation by removing the inertia within a forest that buffers it against change. Similarly, disturbances may enable shrubs and trees to colonize habitats from which they were previously excluded; such change has been suggested for the tundra (Landhäusser and Wein, 1993, Johnstone and Chapin 2006). The microclimate within a forest is very different from that outside the forest, with temperature variations and air movement being lower and atmospheric humidity generally higher. If the forest canopy is removed, this microclimate is lost, and the success of any regeneration will be determined by the atmospheric conditions. Under such circumstances, managers must make the decision whether to try to reduce any major changes in the forest (thereby making it more susceptible to future events), or allow the events to occur (thereby perhaps losing some of the goods and services provided by the existing forest). At the same time, managers must consider the wide range of potential consequences that may be associated with salvage operations (Lindenmayer et al. 2008). Potential strategies are listed in Appendix 6.3.

If the forest canopy is lost, then a manager is faced with important decisions. Current forestry practice for natural forests suggests that attempts should be made to replace the forest with the same species composition as the original forest. However, this fails to take into account that the existing forest

Box 6.2 Fire and drought in southern Africa

Fire regimes of southern Africa are much more under climatic control than human control, as was previously believed (Geldenhuys1994). Therefore it is reasonable to assume that the future fire regime will change, especially in response to the amount and seasonal distribution of rainfall. Contrary to patterns observed in boreal and temperate forests, both the frequency and intensity of fires in southern African subtropical forests *decrease* as the rainfall decreases, because less grass fuel is available to support the fire (Scholes 2004). Furthermore, the fraction of the landscape burned tends to decrease with increasing human population density. A reduction in fire frequency and intensity, all else being equal, is expected to shift the tree-grass balance towards trees (Bond et al. 2003).

Rising temperatures and increasingly variability of rainfall will generally affect surface waters, increasing drought in some regions and causing floods in others. There is likely to be a general decrease of 5–10% of present rainfall, with longer dry spells in the interior and north-western areas coupled with more frequent and severe droughts (Christensen et al. 2007). The fraction of rainfall that becomes runoff is a strong function of rainfall amount, especially in the rainfall range from 500 to 1200 mm. At 500 mm the fraction is about 5%, whereas at 1200 mm it can approach 40%. Below about 500 mm, the rivers are ephemeral, and local people (and some ecosystems) depend on groundwater. Recharge, as a fraction of rainfall, is very small – in the order of 1% – and highly sensitive to changes in net wetness and storm intensity. The projection (low certainty) is for a decrease in groundwater recharge in the dry south-west of southern Africa as soon as 2015 and is expected to reach the east coast by 2060 (De Wit and Stankiewicz 2006). Current policies are encouraging removal of alien vegetation, which has resulted in a major rise in water table in a 30-year period and control of water use. No development decision should be made without taking into account the actual or potential effects of climate change on water resources.

was probably established under different climatic conditions from those at the site today, and that there is a strong possibility that whatever caused the canopy loss will occur again under future climates. There is a widespread assumption that the forest currently at a site is adapted to the current conditions, but this ignores the extent to which the climate has changed over the past 200–300 years, and the lag effects that occur in forests. As a result, replacement of a forest by one of the same composition may no longer be a suitable strategy.

Forest fires are likely to be increasingly important in many parts of the world as climate changes. In many cases, fire hazard may increase, but this may not be universal (see Box 6.2). Forest fires associated with extreme droughts are projected to increase in neotropical forests (e.g. Cox et al. 2004, Nepstad et al. 2004, Scholze et al. 2006), and drought-associated fires have already been noted in the Amazon (Brown et al. 2006, Aragão et al. 2008). Guariguata et al. (2008) argue that this threat can be reduced through the implementation of reduced impact logging (see Putz et al. 2008a), but also point out that like other disturbances, fire hazard is affected by a number of factors, some unrelated to climate change. For example, fires in Brazilian Amazonia can be directly related to frontier advance, and preventing indiscriminate frontier advance will be an important strategy to reduce the impacts of such fires (Laurance and Fearnside 2002, Laurance 2004, Barlow and Peres 2005). However, climate change may increase the susceptibility of the forest to fire, just as it has enabled the spread of bark beetles in the example described in Box 6.3. The impacts will vary from forest to forest, even in an area such as the Amazon Basin, depending on the range of factors that affect the occurrence of forest fires (e.g. Ray et al. 2005, Balch et al. 2008). The co-occurrence of increased fires and increased drought frequency may be particularly important for tropical forests because of their effects on smaller and larger trees, respectively (van Nieuwstadt and Sheil 2005).

The interaction between fire, timber production and other forms of land use is important. Adaptation to a future increase in fire frequency is likely to take a number of forms, depending on the local situation. In some cases, it may involve educating local communities about the risks associated with fires, and encouraging the communities to become involved with fire management. In others, physical precautions, such as the establishment of unvegetated buffer strips between plantations and the surrounding vegetation, may be necessary, although the effectiveness of these needs to be tested. Such strips are already standard practice around blue-gum plantations in southern Australia (Photo 6.2).

In most forest types, the magnitude and frequency of disturbances are likely to increase. This will result

John Innes

Photo 6.2 Fire damage to a blue-gum (*Eucalyptus globulus*) plantation on Kangaroo Island, South Australia (Jarmyn Plantation, planted 2005). This plantation abuts the Flinders Chase National Park, much of which was burnt in December 2008 following a prolonged drought. The plantation was separated from the park by a highway, a roadside strip of remnant native vegetation and a buffer strip (clearly seen in the photo). The fires jumped the highway, burning the roadside vegetation, but did not take hold in the plantation, only scorching marginal trees. Buffer strips such as these may have to be used much more frequently in many areas if plantation investments are to be protected.

in an increase in tree mortality. Dealing with this mortality will be a major issue for many managers. The traditional response to such disturbances has been to salvage the timber, sometimes in ways and at rates that would not be acceptable under normal conditions. For example, the Yukon Government in Canada has issued requests for tenders to salvage one million m^3 of white spruce killed by the spruce bark beetle (*Dendroctonus rufipennis*) in an area that previously had no significant forestry activities. In Victoria, Australia, changes were made to state-authorized harvesting levels to allow for an increase in salvage following extensive mortality caused by fires in 2002–2003 and 2006–2007 (Victoria Government Gazette 2007). The issues surrounding salvage logging are unlikely to be resolved in the near future, but steps taken to decrease the susceptibility of forests to large-scale disturbances will also decrease the likelihood of large-scale salvage operations. A full discussion of salvage logging and its implications is provided by Lindenmayer et al. (2008).

The likelihood of devastating attacks by pathogens will probably vary by domain. For example, some temperate forests, most boreal forests and many plantation forests throughout the world are monospecific or comprise a limited number of species. Such forests are more likely to be impacted by a pathogen benefiting from changed climate conditions. Because of the host-specificity of most pathogens, major outbreaks affecting most or all trees are anticipated to occur more in low-diversity forests than in high-diversity forests, and therefore unlikely in the species-rich forests of the subtropical and tropical domains. However, plantation forests in the tropics may be susceptible to major pathogen attacks, as illustrated by the mortality caused by *Sphaeropsis sapinea* of large areas of Caribbean pine (*Pinus caribaea* var. *hondurensis*) in Venezuela following an El Niño event (Cedeño et al. 2001).

Box 6.3 Mountain pine beetle in British Columbia, Canada

In British Columbia (BC), a total of about 13.5 million ha of lodgepole pine (*Pinus contorta*) has been killed by the Mountain Pine Beetle (*Dendroctonus ponderosae*). The extent of the mortality has been caused by a combination of large amounts of susceptible lodgepole pine in the landscape, exacerbated by reforestation and fire-suppression policies, and warmer winters, which have reduced the winter mortality of the beetles. After several years of tracking the progress of the infestation, the Government of British Columbia responded by raising the annual allowable cut to facilitate large-scale industrial salvage operations. The magnitude of the infestation, along with the Provincial objective to recover as much economic value as possible from the infestation while respecting the other services provided by the forests, necessitated the implementation of measures to help communities deal with economic and social impacts (BCMOF 2006b). Unprecedented levels of financial resources were allocated to combating the infestation, strengthening the long-term competitiveness of the forest industry and facilitating worker adjustment, among other initiatives. The very large volumes of timber that became available coincided with a major downturn in new housing starts in the USA (the major market for BC lumber) and near parity of the Canadian and US dollars, which made Canadian lumber more expensive in the USA. In addition, the recent softwood settlement between Canada and the USA capped the amount of lumber that Canada can export to the USA without triggering significant tariffs.

In 2006, a major flight of the Mountain Pine Beetle (MPB) crossed the Rocky Mountains into Alberta. Almost immediately, Government of Alberta spending on forest health skyrocketed. The objective of the Alberta programme is to contain infestations and prevent the spread northward and eastward into the boreal forest (ASRD 2007a). Short-term management responses are guided by an assessment of the current status and risk of spread. Three MPB management priority zones are designated annually – Leading-Edge, Holding and Salvage – which determine levels of management and control strategies (ASRD 2007b). An elaborate decision support system was constructed to aid in the timely identification of Level 1 (individual tree treatment) and Level 2 (block or patch harvesting of infested areas) treatment priorities within these zones. The current level of funding supports Level 1 treatment of 120 000 to 180 000 locations per year. Longer-term management responses are guided by the objective to reduce the amount of susceptible pine by 75% over the next 20 years. This is primarily concerned with altering age structure rather than species composition (which must remain the same at the landscape level). At the time this report was completed, more effort is being directed to Level 1 search-and-destroy tactics than to Level 2 tactics to reduce amount of vulnerable stands. The Government of Alberta also took steps to clarify the roles and responsibilities of different organizations on different land tenures to manage the infestation, in part a response to the softwood lumber agreement (ASRD 2007c).

The different nature of the management response to the MPB infestation in BC and Alberta deserves mention. In Alberta, mobilizing management response to the infestation occurred much more quickly than in BC. Alberta witnessed BC's experience and therefore was able to envisage what the scale of the infestation might become in planning their initial response whereas BC had no precedent to work from. Both jurisdictions have multiple objectives in responding to the infestation that include dealing with the short-term consequences of the epidemic and managing for multiple values, but BC's response is more focused on recovering economic value and Alberta's is more focused on stopping the spread of the MPB and associated damaging impacts on forests. On-the-ground salvage in BC is largely being carried out by industry, whereas in Alberta the Alberta Government is making a tremendous effort to contain the infestation at the scale of individual trees. Under BC's forest legislation, the licensees have an obligation to re-forest any cut areas. In most cases, lodgepole pine is being used to reforest the salvage sites, a practice that will result in large areas of even-aged lodgepole pine forest and encourage the re-creation of the same conditions that allowed the current epidemic to occur. Given that current climatic predictions are for progressively warmer winters, it seems likely that the forests being replanted today will be vulnerable to future outbreaks. Alberta on the other hand has adopted a very explicit policy to reduce vulnerable stands across the landscape by altering age structure and therefore has more explicitly incorporated future climate change considerations into its management response than BC.

Which of these two approaches will ultimately have more success in achieving sustainable forest management objectives? This may only be known with time. To aid in any future retrospective assessments, a typology for classifying sustainable forest management plans according to how they address climate change has been suggested. It consists of a matrix that categorizes plans into one of four types: (1) proactive-direct, (2) proactive-indirect, (3) reactive-direct, and (4) reactive-indirect (Ogden and Innes 2008a). This typology recognizes that adaptation to climate change can be carried out in response to, or in anticipation of, the changes and may either directly or indirectly acknowledge climate change as a driver of change. According to this typology, the BC response may be characterized as reactive-indirect and the Alberta response as both proactive-direct and reactive-indirect. To date, there is little research available on the cost-benefits of these differing approaches and how successful these approaches will be in addressing and managing the risks posed by climate change.

6.4 Management Options for Maintaining and Providing Provisioning Services

6.4.1 Forest Management Strategies to Maintain the Productivity of Forest Ecosystems under Climate Change

Changes in the productivity of forests associated with climate change will very much depend on the local situation. In some cases, productivity is likely to increase (e.g. Ollinger et al. 2008), whereas in others, there will be a loss in productivity (Clark et al. 2005, Feeley et al. 2007). There is already evidence of increased biomass in some tropical forests (e.g. Baker et al. 2005, Phillips et al. 2008), and increased growth has also been reported in temperate and boreal forests (e.g. Spiecker 1999). Another possibility is that productivity may increase and then fall as the growth response saturates (Phillips et al. 2008). A meta-analysis of tree productivity responses (Boisvenue and Running 2006) has suggested that where water is not limiting, productivity will generally increase. This is, however, very complex, and a range of different factors are involved in determining the final productivity of forests. Some of these are independent of climate change, such as nitrogen deposition, whereas others are directly related (e.g. increasing concentrations of atmospheric carbon dioxide – Laurance et al. [2005] or increased solar radiation as a result of reduced cloudiness – Lewis et al. [2004]) or indirectly related (e.g. increased nutrient deposition from increasing forest fires – Artaxo et al. [2003]).

While most studies to date have concentrated on the potential impacts of climate change on the production of fibre resources, increasingly there are concerns about the productivity of non-timber products such as medicines and foods. Relatively little information is available in the scientific literature about the sustainable management of such products (but see Peters 1994 and Shanley et al. 2002), and even less is known about their vulnerability to climate change.

Box 6.4 presents the results of a study on the effects of selected management regimes on the growth of different tree species in a Scandinavian boreal forest. Potential responses (see Appendix 6.4) will be the cumulative result of a number of different factors. These include water availability, response to elevated carbon-dioxide levels, changes in vegetation patterns, changes in pathogen distributions and

Box 6.4 Productivity and the current patterns of timber production – an example on management to adapt forests to the climate change in the boreal conditions (Kellomäki et al. 2007)

As the simulation example for the boreal forests in Chapter 3 showed, the productivity of forest ecosystems may be reduced, because climate change may create a suboptimal environment for Norway spruce, especially in southern parts of Finland (6062 ºN). Obviously, there are two main tasks in adapting to the climate change: i.e. to maintain (i) the productivity of the forest ecosystems and especially (ii) the growth of Norway spruce if the current patterns of timber production are preferred in the future. In the following simulation example, several strategies were applied in reformulating the current management to meet the changes in the climate.

First, the length of the rotation was reduced by making the terminal cut (clear cut) earlier than in conventional timber production but still aiming at producing saw timber and pulpwood. *Second*, Norway spruce was replaced by Scots pine or birch on sites of medium fertility, and Norway spruce was preferred only on sites with high fertility, if it had occupied the site prior to the terminal cut. *Third*, a more southern provenance of Norway spruce was used in planting. Regarding Norway spruce, the new provenance was described by changing the maximum and minimum temperature sum in the temperature sum multiplier of the growth model. Now, the maximum values were 2500 d.d. (previously 2060 d.d.) and the minimum value 360 d.d. (previously 170 d.d). The outlines of the model and the input representing the climate and the initialization of the simulations are given the Chapter 3.

Table 6.1 shows that the reduction of rotation length reduced the mean growth of Norway spruce (up to 16%) but increased the total growth representing all tree species (up to 28%), because the growth of Scots pine and birch increased. The increase was the largest in the south, where the total mean growth increased up to 35%. This was much more than that obtained when preferring Scots pine on sites of medium fertility (12%); i.e. the increased growth of Scots pine did not compensate the reduction in the growth of Norway spruce and birch. On the contrary, when birch was preferred the total growth increased most (38%). The use of the more southern ecotype of Norway spruce also

Box 6.4. continued

Table 6.1 Mean growth of different tree species in southern and northern Finland (2070–2099) under selected management regimes (Kellomäki et al. 2007). South refers the forests below 62°N and north to the forests above 62°N. *Myrtillus* **site type refers to the sites of medium fertility.**

Management strategy	Mean growth, $m^3 ha^{-1} yr^{-1}$ (% of that under the current management rules)			
	Scots pine	Norway spruce	Birch	Total
Strategy 1: Management with no modifications of the current management rules.				
South	2.81	0.26	3.62	6.69
North	3.19	0.58	0.84	4.61
Total	2.96	0.39	2.49	5.84
Strategy 2: Management with terminal cut, when the minimum diameter requirement is exceeded.				
South	3.42 (+22)	0.24 (–8)	5.36 (+48)	9.02 (+35)
North	3.70 (+16)	0.49 (–16)	1.07 (+27)	5.26 (+14)
Total	3.54 (+20)	0.34 (–13)	3.62 (+45)	7.50 (+28)
Strategy 3: Preferring Scots pine if the site previously occupied by Norway spruce. Terminal cut at the minimum diameter requirement.				
South	4.06 (+44)	0.17 (–35)	3.29 (–9)	7.53 (+13)
North	3.99 (+25)	0.39 (–33)	0.70 (–17)	5.08 (+10)
Total	4.03 (+36)	0.26 (–33)	2.24 (–10)	6.53 (+12)
Strategy 4: Preferring birch on *Myrtillus* site if previously occupied by Norway spruce. Terminal cut at the minimum diameter requirement.				
South	3.12 (+11)	0.17 (–35)	6.79 (+88)	10.08 (+51)
North	3.53 (+11)	0.49 (–16)	1.14 (+36)	5.16 (+12)
Total	3.29 (+11)	0.30 (–23)	4.49 (+80)	8.08 (+38)
Strategy 5: Preferring Norway spruce of more southern ecotype. Terminal cut at the minimum diameter requirement.				
South	3.04 (+8)	0.67 (+158)	5.56 (+54)	9.27 (+39)
North	3.60 (+13)	0.44 (–24)	1.23 (+46)	5.27 (+14)
Total	3.27 (+10)	0.57 (+46)	3.80 (+53)	7.64 (+31)

increased the total growth (31%). It seems that a proper choice of tree species and provenance are the basis for an adaptive management when aiming at maintaining the productivity of forest land under the climate change. Furthermore, reduced rotation length with more rapid turnover of forest resources may help to maintain the productivity and makes it possible to modify the management strategies to meet changes in site conditions under the changes in climate.

a range of other factors, making predictions very difficult (Kirilenko and Sedjo 2007). The modelling studies that have been undertaken to date are highly dependent on the factors included in the models, and different approaches can generate divergent results (for example, an increase versus a decrease in productivity – cf. Girardin et al. 2008). It is also apparent that local factors play a major role in determining the productivity responses (e.g. Loustau et al. 2005, Su et al. 2007), making broader extrapolations difficult. This means that models must be carefully calibrated using local, empirical information and that the results of any models should only be extrapolated beyond the area for which they were derived with great care (Nigh 2006). In addition, growth models are often based on biophysical processes and do not account sufficiently for social considerations. Despite these constraints, it is evident that improved silviculture could increase the productivity of both temperate and boreal forests (Nabuurs et al. 2008) and tropical forests (Peña-Claros et al. 2008).

Many productivity issues are now being addressed through genetics. Genetic studies are likely to shed some light on the extent to which forest trees will be able to adapt to climate change. Projects such as EVOLTREE (Kremer and Six 2008) are aimed at identifying the genes that control the adaptive ability of trees and examining their frequency amongst forest trees. With the recent publication of the draft sequence of the poplar (*Populus trichocarpa* Torr. & Gray ex Brayshaw) genome (Tuskan et al. 2006), and the much larger *Pinus* genome expected soon,

Box 6.5 The use of genetically modified organisms

While not discussed in the definition of sustainable forest management provided in Chapter 1, there are some groups with their own definition of SFM, such as the Forest Stewardship Council, that consider the use of genetically modified trees to be irreconcilable with the principles of SFM. The use of genetically modified trees has been listed as one possible adaptation option – whether or not it is adopted by a particular manager will depend on a range of factors, including whether or not the use of such trees is legal within a country and whether or not the public will accept them. There are strong arguments both for and against such use, and the reader is referred to Strauss and Bradshaw (2004) for a discussion of the subject.

there will be a better understanding of the genomic attributes that affect the phenotypic performances of trees growing in different environments (Nelson and Johnson 2008). For a short note on genetically modified organisms see Box 6.5.

There are concerns that the productivity of plantations in temperate and boreal regions may be adversely affected by climate change, with many such plantations potentially suffering from dieback due to drought and other stresses (Sohngen et al. 2001). As a result, there may be greater global demand for forest products from tropical and subtropical forest plantations (Guariguata et al. 2008). The ability of such plantations to meet this demand will depend on how well adapted they are to the evolving climate. Tropical plantations are more likely to remain viable under future climate than temperate and boreal plantations, as the shorter rotation times will reduce the risk of maladaptation and damage by extreme events during a particular rotation. Plantation species such as *Casuarina equisetifolia* (used in India), *Eucalyptus grandis* (used in Brazil), *Gmelina arborea* (used in Malawi and west Africa) and *Leucaena leucocephala* (used in the Philippines) are all fast-growing and reach maximum growth rates relatively early (Evans and Turnbull 2004).

The principles of sustainable forest management mean that the rate of timber removal should be appropriate for the forest while maintaining all other ecosystem services. In the past, this has been interpreted as ensuring that a sustained yield of timber is maintained. However, today, it is more determined by the range of services provided by forests and the values that a manager is seeking to maintain. Despite this, many jurisdictions still attempt to determine an annual allowable cut. However, very few, if any, cut determinations factor in predicted changes in productivity associated with climate change. This is an important omission that needs to be rectified.

6.4.2 Forest Management Strategies to Maintain the Tangible Socio-Economic Benefits from Forests under Climate Change

While changes are likely to occur in the distribution and composition of forests, the impact of these changes on the production of tangible socio-economic benefits from forests will be strongly influenced by the markets for those socio-economic benefits and other potential uses of forest land. For example, while some ecological models have suggested that declines in productivity or large-scale losses associated with drought and fire may occur (e.g. Botta and Foley 2002, Oyama and Nobre 2003, Cox et al. 2004), economic models of the forest sector have suggested that when producers implement adaptation options in forest management for timber and wood products, globally the impact on the forest sector is small (Irland et al. 2001, Sohngen et al. 2001, Joyce 2007). These studies suggest that though there may be some local negative impacts, the impacts are more likely to be positive for a larger share of the population. Market forces can shift the supply between regions in the world, between landowners within a region, and between softwood and hardwood harvests (Kirilenko and Sedjo 2007). When climate change causes large-scale, widespread dieback, timber prices will be depressed due to anticipatory harvest and salvage.

The potential decrease in the economic resilience of forest-dependent communities is a trend of particular concern. This has already been seen in some communities, as in central British Columbia where forests have been devastated by the mountain pine beetle (Parkins and MacKendrick 2007). However, any community currently dependent on forestry is at risk of destabilization, some more seriously than others. There is likely to be a high level of variation in the ability of forest-dependent communities to adapt to climate change (see Chapter 4), but there have been relatively few rigorous studies investigating this. One study in northern Europe revealed that

Photo 6.3 Clearance of montane tropical rainforest for agricultural gardens at Poring, Sabah, Malaysia. Any steps to manage tropical forests more sustainably must take into account the complex relationships between the welfare of local people and global concerns such as climate change. The social factors that force people to burn forest need to be examined carefully and addressed. The adverse impacts of climate change may actually result in some forest-dependent people relying even more on forest resources, leading eventually to over-exploitation and forest degradation and loss.

the communities in Norrbotten (Sweden), Lappi (Finland) and Arkhangelsk oblast (Russia) differed markedly, primarily because of their varying degrees of dependence on natural resources and their ability to counteract negative effects (Lundmark et al. 2008).

The top-down imposition of adaptation strategies could lead to conflict amongst different stakeholder groups (Deshingkar 1998). There is therefore a need for the careful evaluation of local preferences (Keskitalo 2008, Ogden and Innes 2008b) and implementation of the preferred adaptation options. In some cases, local communities may lack understanding of the nature or extent of the problems faced (cf. Guariguata et al. 2008), or may have difficulty perceiving climate change as a risk (e.g. Davidson et al. 2003). In such cases, the problems may well become manifest as a result of disturbances. Fires, pathogen outbreaks or forest dieback may result in major short-term changes in the services provided by forests, causing immediate impacts on the livelihoods and welfare of local people. Adaptive approaches will require the sharing of knowledge and the integration of informal networks, yet this may be difficult to achieve (see for example, a discussion of the problems facing such an approach in Canada by Wellstead and Stedman, 2007).

In tropical areas, trees planted by smallholders may play an important part in the landscape, providing a range of goods and services. Such trees may be impacted by climate change, and adaptation mechanisms are required (Guariguata et al. 2008). Smallholders may need external assistance in implementing adaptations but, at the same time, participatory approaches to adaptation, such as participatory tree improvement (Simons and Leakey 2004) may offer considerable potential.

While relatively few studies exist, it can be expected that communities that depend on a single or very few forest products will be more vulnerable to climate change (or any other external shock) than communities that use a whole range of products, several of which may have different responses to climate change (Parkins and MacKendrick 2007). As pointed out by Thomas and Twyman (2006), the greater the diversification of a local economy, the less its vulnerability to climate change is likely to be because of its 'room for maneuver'. Potential strategies to maintain the tangible socio-economic benefits are listed in Appendix 6.5.

6.5 Management Options for Maintaining and Providing Regulating Services

6.5.1 Forest Management Strategies to Maintain Soil and Water Resources under Climate Change

Climate change may have major impacts on the environment, through droughts, floods, increased erosion, landslides, melting of permafrost and other impacts. Some of these phenomena, such as droughts, soil erosion and landslides, are natural processes that can be affected by human activities. Consequently, the forestry community has long recognized that protection forests are an important means to safeguard infrastructure and human life, and are widely used in mountain areas. However, existing strategies towards the maintenance of protection forests may have to be changed in the light of climate change, and new strategies to cope with some of the other changes that climate change will induce may have to be developed. The potential management strategies to maintain soil and water resources under climate change are listed in Appendix 6.6.

Protection forests can be natural forests (Sakals et al. 2006, Wilford et al. 2006) or planted forests (Evans and Turnbull 2004). They are also increasingly being used to stabilize sand dunes and desert margins in areas affected by desertification. For example, in China, the Three North Shelterbelt Development Programme and the Shelterbelt Development Programme along the Yangtze River Basin has been designed to alleviate desertification in the Three North Region. If successful, the current phase of the programs will afforest 9.46 million hectares of land and bring 1.3 million ha of desertified land under control between 2001 and 2010. By the programmes' end, forest cover in the programme areas will have been increased by 1.84%, 11.33 million ha of farmland will have been put under shelter, and 12.66 million hectares of desertified, salinized and degraded grasslands will have been protected and rehabilitated. In the lower-middle reaches of the Yangtze River the programme will afforest 18 million ha of land, improve 7.33 million ha of low-efficiency shelterbelts and regulate and protect 37.33 million ha of existing forests (Wang et al. 2008). To enable them to fulfil their expected functions under future climates, it will be necessary to manage protection forests actively. If they are left unmanaged, the evidence that we have suggests strongly that they risk being degraded and losing their protective abilities.

In many countries, forested catchments provide an important source of drinking water. Water demand is expected to grow globally, but current water-management practices are very likely to be inadequate to cope with the effects of climate change (Kundzewicz et al. 2007). The capacity of the forest ecosystem to purify water is an important service, obviating the cost of expensive filtration plants. Consequently, management operations need to be undertaken with care. For example, it may be necessary to leave a buffer strip of forest between a stream or river and any area used for forestry operations (e.g. Laurén et al. 2005).

There may, however, be negative effects for soils and water associated with forests and their management. In particular, forest roads are an important source of erosion (Grace and Clinton 2007), and major adaptations to their design and use will have to be made to avoid increased erosion associated with the more intense rainfall events that are expected in many areas (e.g. Bruijnzeel 2004). The interaction between stormflow events and soil changes associated with harvesting activities will require particular attention (cf. Waterloo et al. 2007). While the effects of roads are clear, the impact of afforestation on processes such as infiltration are currently unclear (e.g. Ilstedt et al. 2007) and therefore difficult to predict under future climates.

Forests use more water than grasslands, and in areas where water supply is an issue, afforestation projects may result in lowered water tables and reduced stream flows (e.g. Buytaert et al. 2007, Dye and Versfeld 2007, Trabucco et al. 2008). This is a complex subject with little agreement amongst hydrologists and foresters on many of the relationships between forest cover and water supply under different conditions (Vertessy et al. 2003, Calder 2005, Jackson et al. 2005, Nambiar and Ferguson 2005, Chang 2006, van Dijk and Keenan 2007).

Generally, current efforts to maintain the quality and quantity of soils and water associated with forests may have to be intensified. Most current efforts focus on minimizing damage through prescriptive or legislative approaches, and there is a lack of monitoring to determine the effectiveness of such approaches.

6.5.2 Forest Management Strategies to Maintain and Enhance Forestry's Contribution to Global Carbon Cycles under Conditions of Climate Change

The importance of forests in global carbon budgets was emphasized by the United Nations Framework Convention on Climate Change in December 2007. The Bali Action Plan built on the IPCC's Fourth Assessment Report that found that forestry (including deforestation) contributes 17% of the total annual carbon emissions (Rogner et al. 2007), and defores-

Photo 6.4 Protection forest consisting of Atlas Cedar (*Cedrus atlantica*) in the High Atlas Mountains, Morocco. Such forests play an important role in stabilizing steep slopes and protecting people and infrastructure from natural hazards such as rockfall and landslides. However, there is evidence that climate change may be destabilizing this species (Chenchouni et al. 2008), and management practices, such as the choice of species in afforestation programmes, may have to be adjusted.

tation alone contributes 5.8 $GTCO_2$/yr (Nabuurs et al. 2007). Particular emphasis is now being placed on reducing emissions from deforestation and forest degradation (REDD). Forests represent an important means of mitigating climate change (Canadell and Rapuach 2008), but they will be effective in doing so only if the forests can adapt to the changes in climate that will occur in the future. The total potential of forests to reduce atmospheric carbon is limited given current atmospheric releases, although in some tropical countries emissions from deforestation may be greater than other forms of GHG emissions. However, reducing emissions from forests and using forests for carbon sequestration can both help to reduce the current rate of increase in atmospheric CO_2 while other options are being pursued (especially a reduction in the release of CO_2 from the burning of fossil fuels). In addition, reducing deforestation and forest degradation will have a number of other benefits, including the protection of biodiversity (O'Connor 2008) and promoting the relief of poverty (Singh 2008).

Mitigation and adaptation are not readily separated when considering carbon sequestration. Many adaptation strategies also need to take into account the potential mitigation, especially as mitigation represents an ecosystem service for which there is potential for payment (Canadell and Rapuach 2008). Mitigation may therefore represent a potential means by which adaptation measures could be financed (Osafo 2005, Santilli et al. 2005, Silva-Chavez 2005, Nepstad et al. 2007, Canadell and Raupach 2008, Bellassen and Gitz 2008, Putz et al. 2008b), and such measures are therefore included in this report (Appendix 6.7).

Large-scale afforestation has been suggested as a means to increase the sequestration of atmospheric CO_2 by forests, even though such projects are unlikely to have a major impact on global carbon sequestration (Strengers et al. 2008). Such recommendations often come from groups with strong vested interests, including the forestry and biofuel lobbies. However, it is important to note that afforestation and reforestation also reduce albedo, particularly in high-latitude regions, and thereby can contribute to atmospheric warming. As a result, the benefits associated with afforestation and reforestation may be least in the boreal domain, and feedback loops should be carefully considered when developing strategies to increase carbon sequestration (Bala et al. 2007, Chapin et al. 2008). Such results, combined with the adaptation benefits associated with short rotations associated with tropical plantations, strongly suggest that afforestation efforts should be focused in tropical and subtropical regions. However, the impact on local livelihoods of land-use conversion needs to be considered when assessing the potential costs and benefits of afforestation projects aimed at carbon sequestration (Leach and Leach 2004, van Noordwijk et al. 2008, Zorner et al. 2008).

The carbon balance of some areas could be adversely affected by climate change, and forest carbon management could play an important part in mitigating any adverse effects. For example, climate models show strong agreement that the peatland forests of South-east Asia will experience increasing dryness, making them more susceptible to drying out and to fire (Li et al. 2007). Wildfires and insect outbreaks have changed the forests of Canada from being a CO_2 sink to being a CO_2 source (Kurz et al. 2008a, 2008b). Such changes may require drastic management actions, particularly in honouring a country's Kyoto commitments.

6.5.3 Forest Management Strategies to Regulate Human Diseases

Under criteria and indicator schemes adopted as part of sustainable forest management, forest health and vitality is usually taken to refer to the health and vitality of trees, particularly those of commercial value. However, the concept should be extended to the entire forest ecosystem and, in addition, should cover the health of forest workers and other forest-dependent people, as they are a part of the forest ecosystem. This approach is consistent with the rapidly increasing evidence for the close connections between human health and forests (e.g. Colfer et al. 2006, Colfer 2008a, 2008b) and the recognition that these connections could be affected by climate change (Menne et al. 2002). For example, there is considerable evidence that bat-borne viral zoonoses may be impacted by climate change, and it has been hypothesized that the SARS coronavirus, Ebola fever and Nipah encephalitis are all in some way related to direct or indirect changes in the relationships between people and forest-dwelling bats (Gonzalez et al. 2008).

The strategies listed in Appendix 6.8 indicate that a range of activities are necessary. Many of these relate specifically to tropical and subtropical forests, but it is important to remember that there are also important interactions between forests and human health in the temperate and boreal zones. In particular, forests within and close to urban areas are likely to play an increasingly important role under future climates. There is already evidence that forests can alleviate the effects of extreme temperatures, as shown during the 2003 heatwave in Europe (Renaud and Rebetez in press). As the amount of recreational time available to people increases, there is likely to be increased demand for recreation in forests, as well as the possibility of using them for therapeutic purposes. Visits to forests can increase the human natural killer cell activity (Li et al. 2008a, 2008b), reduce stress (Yamaguchi et al. 2006, Morita et al. 2007), reduce blood glucose levels (Ohtsuka et al. 1998) and generally improve mental and physical health (Ohira et al. 1999). As a result, in countries such as Japan and South Korea, there is a strong interest in health-related recreational activities in forests.

6.6 Management Options for Maintaining and Providing Cultural Services

6.6.1 Cultural Values and Local Knowledge

Forest cultural values are generally deeply ingrained (cf. Harrison 1992, Nakashima 1998, Hayman 2003). Climate change may alter some of the cultural attributes of forests. The prediction of such changes and the development of adaptation strategies for them are difficult. For example, the ability of some indigenous groups to hunt, trap and fish in forests represents an important survival process for some groups. However, such actions may also have strong cultural significance (e.g. Flood and McAvoy 2007, Griffin 2007, Levang et al. 2007) and may be central to maintaining some traditional aspects of the cultures of forest-dependent people, such as language. This is not restricted to indigenous groups. In the temperate and boreal zones, hunting remains a strong institutional and cultural tradition for many people, and its loss may be vigorously resisted (as demonstrated in the United Kingdom when the government banned fox-hunting). In relation to climate change, institutions will have to be sufficiently flexible to ensure that it is possible to maintain cultural traditions as the forests change. In the case of hunting, new potential quarry species may replace traditional ones, and changes to legislation may be required to ensure that these can be legally hunted.

Many traditional practices are not always easily 'translated' into the language of modern forest science (Berkes et al. 2000, Kimmins 2008). However, they have enabled traditional societies to cope with environmental change in the past (e.g. King et al. 2008b) and could provide these communities, and society in general, with adaptive management approaches and specific forest-management techniques for dealing with increased climate variability, changes in the frequency and intensity of natural

Photo 6.5 Sacred forest grove near Lhunze in Tibet, China. The intangible benefits associated with such forests are impossible to quantify, and it is very uncertain how climate change will affect them.

forest disturbances (such as storms, fire, drought, alien invasive species), alterations in forest structure and composition, and other expected impacts of climate change (Scotti and Cadoni 2007). Such adaptations may, however, be compromised by other, non-climatic changes, such economic and legal constraints on traditional activities (e.g. Xu et al. 2005, Tyler et al. 2007). Potential adaptation strategies to provide and maintain cultural services are listed in Appendix 6.9.

6.6.2 Forest Management Strategies to Maintain the Aesthetic Services Provided by Forests

It is also extremely difficult to determine how adaptation might maintain the aesthetic values associated forests, as there are major cultural differences in how forest aesthetics are considered. For example, major disturbances such as storms and fires are likely to reduce the aesthetic value of forests (e.g. Hunt and Haider 2004), but the mortality of individual trees may create opportunities for more biodiversity, increasing the aesthetic and recreational (such as for bird-watching) opportunities of the forest. Relatively little work has been done in this area, although there are a few studies (e.g. Galečic et al. 2007), and it is likely that more research will be conducted as the occurrence of disturbances to forests used for recreation and for visual quality increases.

6.6.3 Forest Management Strategies to Maintain the Spiritual Services Provided by Forests

Spiritual values are often assumed to be related purely to indigenous groups, because such groups are often recognized as having very strong spiritual links to the land. This is illustrated by the Aboriginal concept of country, expressed by Rose (1996) as: ‘Country in Aboriginal English is not only a common noun but also a proper noun. People talk about country in the same way that they would talk about a person: they speak to country, sing to country, visit country, worry about country, feel sorry for country, and long for country. People say that country knows, hears, smells, takes notice, takes care, is sorry or happy. Country is not a generalised or undifferentiated type of place, such as one might indicate with terms like like “spending a day in the country” or “going up the country”. Rather, country is a living entity with a yesterday, today and tomorrow, with a consciousness, and a will toward life. Because of this richness, country is home, and peace; nourishment for body, mind, and spirit; heart’s ease.’ However, spiritual and cultural links extend far beyond indigenous groups to all communities (Varner 2006). The knowledge that accompanies such links may be of vital importance in preserving elements of the landscape in the future (e.g. Gómez et al. 2006, Agnoletti 2007). A distinction needs to be made, however, between spiritual and religious values associated with forests. The former are not necessarily associated with any particular religion, whereas the latter always are. Forests or stands within forests with religious significance are frequently referred to as sacred groves (e.g. Gaisseau 1954, Spindel 1989, Decher 1997, Tiwari et al. 1998).

As in a number of areas associated with the cultural services provided by forests, very little research has been undertaken on the effects that climate change may have on the spiritual services provided by forests. However, any increase in the occurrence of forest disturbances is likely to have impact on the spiritual value of the forests. This is particularly true given that many spiritual values are associated with larger and older trees (Alban and Berwick 2004, Lewis and Sheppard 2005). While there have been some attempts to examine the spiritual and religious values of forests (e.g. Melo Filho et al. 2008), such studies have not yet factored in the potential impacts of climate change.

6.6.4 Forest Management Strategies to Maintain the Educational Services Provided by Forest

In the field of education, there is a tendency for conservative approaches to dominate (Innes 2005). The adaptation of forest management to climate change will require new approaches and new ways of thinking, extending well beyond the linear programming methods used in some forestry textbooks (e.g. Davis et al. 2001). More recent textbooks are beginning to include such approaches (cf. Bettinger 2009). In some areas, the conservative approach to forestry has resulted in significant drops in the numbers of students taking up the subject (Leslie et al. 2006, Nyland 2008). This is likely to be a significant problem in many developed countries in the future. In developing countries, the problem is more one of education capacity, combined with the loss of trained foresters from the profession. For example, in much of Africa, there has been a significant loss of expertise in rural workforces due to mortality induced by HIV/AIDS (Anaeto and Emenyonu 2005). Conversely, forestry has been proposed as an important tool in the fight against the HIV/AIDS pandemic in sub-Saharan Africa (Barany et al. 2001, Topouzis 2007), but its role could be compromised by the failure of forest managers to adapt to climate change.

Where they exist, institutions concerned with the maintenance of management standards, such as professional forestry associations, can be equally conservative. Only a few have mandatory continuing education programmes for their members, and there is therefore a significant problem in keeping members up to date with the latest information about climate change. For example, in a survey of forestry practitioners (which included both professional foresters and others with a professional interest in forestry) in north-west Canada, 44% considered that they had poor knowledge of how to respond to climate change (Ogden and Innes 2007b), and climate-change risks are rarely perceived by foresters and forest managers working in tropical forests (Guariguata et al. 2008). This may be because of a lack of information available to managers at appropriate spatial and temporal scales.

6.6.5 Forest Management Strategies to Maintain the Recreational Services Provided by Forests

A variety of recreational activities occur in forests, and climate change may have an impact on many of these. For example, many people visit forests for bird-watching, but birds are particularly sensitive to climate change, and changes in bird populations have already been observed in high-visit areas such as the northern Appalachians of the USA (King et al. 2008a). The importance of forests for recreation is likely to grow in many areas, and the health risks associated with increased numbers of visitors will require careful monitoring (Buckley et al. 2008). It is not clear how climate change will affect this growing demand for recreation. Urban forests are likely to provide a certain amount of relief from heat stress, but only if they maintain their canopies. Consequently, disturbances, especially storms and fires, are likely to reduce the potential value of forests for recreation. The adaptation strategies of the public may come into conflict with those of forest managers, since forest managers may seek to exclude or at least restrict visitors during periods of particularly high fire hazard. Conflicts such as this will need to be resolved locally on a case-by-case basis, reflecting the unique management needs associated with urban forests (Carreiro et al. 2008).

A particular concern is the role that recreation may play in causing problems in forests. For example, the occurrence of *Phytophthora ramorum* (sudden oak death) is known to be accelerated by the presence of hikers, who spread the disease along trails (Cushman and Meentemeyer 2008). Future recreation management will increasingly need to consider the risks associated with public visits to forests.

6.7 Conclusions

It is possible to draw a number of conclusions from the analysis undertaken for this chapter.

- **Learning from past shortcomings in SFM**
  Many of the management options listed in this chapter are closely related to the practice of sustainable forest management (SFM). However, the global forest sector has been slow to adopt the practices of SFM, particularly in developing countries. Much greater efforts are required nationally and internationally to ensure the more responsible stewardship of the world's forests. These actions need to get out of the 'forest' box, learn from past shortcomings and involve actors from other sectors. Global forests are essential to the mitigation of climate change, and also represent a resource used by billions of people. All actors need to work together more effectively to ensure that forests are better managed in all regions.
- **Sustainable forest management options**
  The diversity of forests throughout the world, the differences in management arrangements, and the uncertainties associated with predicting how climate will evolve at any particular location, all make it impossible to provide prescriptive recommendations for the adaptation of forests to climate change. A large number of different potential strategies exist, applicable at strategic or operational levels. The choice of strategies will depend on local situations, but a key conclusion is that many of the actions associated with sustainable forest management present 'no regrets' decisions for forest managers. The strategies listed in this chapter are all consistent with sustainable forest management, although clearly it would not be possible to implement every strategy on a particular piece of ground. Conversely, implementing only the strategies associated with a particular service may cause an imbalance in the overall management of the forest. Instead there are many effective tools that can be used to ensure that tradeoffs are optimized to particular situations. The uncertainties associated with projections of climate change and associated impacts emphasize the need to identify robust management strategies – those that are likely to achieve the objectives of sustainable forest management and are likely to perform well across a wide range of potential future climate conditions. Robust strategies must also be flexible and responsive to new information and therefore incorporate the principles of adaptive management.
- **Taking advantage of opportunities**
  While climate change will present many difficult challenges for forest managers around the world, there will also be opportunities. In some regions, it will be possible to expand forest cover or increase forest productivity. There should be sufficient flexibility within forestry policies to ensure that these opportunities can be developed, always bearing in mind that land potentially becoming available for forests may also be important for alleviating global, national or regional food supply problems.
- **Management to reduce vulnerability to storms, fires, insect pests and diseases**
  In all scenarios and all domains discussed in this report it is very likely that storms, fires, insect attacks and diseases will occur more frequently and at greater intensity. Prevention will require extensive communication networks and monitoring schemes at regional and national level, as well as specific management practices (e.g. controlled burning, sanitary cuts) at local level. This will require considerable investments in infrastructure (communications, watchtowers, road network), training and equipment.
- **Need for more management**
  For adaptation of forests to climate change, a *laissez-faire* approach to forests management will be inappropriate. Active management will be required if specific management values are to be maintained. This will be particularly true for protection forests. For example, in forested watersheds where no management takes place to minimize potential impacts on water supply, it may be necessary to adopt a more active approach. The need for more management implies additional costs, and it is important, particularly in developing countries, that opportunities to finance these costs through payments for mitigation services are realized. To do this, it is essential for decision-makers to recognize that adaptation and mitigation are closely linked. To date this thinking has not been included in many of the national and international policies developed in relation to climate change, At the same time, it is also important to recognize that failure to adopt management actions now is likely to result in increased costs in the future. Managers need to be pro-active and adopt strategies that may be beyond all past experiences.
- **Adaptive management**
  A key strategy applicable to all forests, regardless of which scenario is used, is adaptive co-management. While much research has been undertaken, there are large gaps in our knowledge of the impacts of climate change and the most appropriate adaptation strategies. For individual managers, the most appropriate management approach in many cases (but not all) given such uncertainty is adaptive co-management. Policies and regulations must be sufficiently flexible to

allow adaptive co-management to take place, and there needs to be a recognition that mistakes will be made. It is important that lessons are taken from such mistakes, and that they are rectified as quickly as possible. Commitments at several different levels are required – not just between scientists and managers but also amongst policy-makers and the public. Effective mechanisms are required to ensure that existing and novel adaptation approaches can be readily 'translated' into policy and practice.

- **Monitoring**
  A key aspect of adaptive co-management is adequate monitoring. This can be undertaken at a range of scales, from the stand to the nation. Stand- and forest-level monitoring are required to determine whether particular management strategies are being effective. National monitoring is required for a number of reasons, such as carbon accounting and as a means of determining how forests and forest communities are adapting to climate change.
- **Integrating ecological, economic and social research**
  Many current forest management practices may be adopted to facilitate adaptation of forests to climate change. However, these practices were developed under climates that may not reflect future novel climates, and proper experimentation to determine the forest response to new and novel management practices under a changing climate will be valuable. Further, the human response to change will be critical in taking advantage of opportunities under the changing climate. Increasing our understanding of what policies and incentives will facilitate human adaptation at the individual, community, company and government level will be important to develop on-the-ground management practices to adapt forests to climate change.
- **Limits to adaptation, limits to mitigation**
  Over the long term, forest managers must make greater efforts than currently both to mitigate and adapt to climate change. Even the most stringent mitigation efforts cannot avoid further impacts of climate change, which makes adaptation essential. However, it is important to understand the limits of adaptation. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt. There is high confidence that the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by 2100 by an unprecedented combination of change in climate, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g. land-use change, pollution, over-exploitation of resources). Adaptation alone is not expected to be able to cope with all of the projected effects of climate change, and especially not over the long run as most impacts increase in magnitude. Adaptations to resource-management policies and practices may only buy ecosystems additional time to adjust to a changing climate until broad global action on reducing greenhouse gas emissions takes effect. In addition, failure to adapt forest-management practices and policies to the realities and uncertainties associated with climate change may impact the ability of forests to mitigate climate change. Therefore, both adaptation and mitigation are essential and complementary approaches to climate change.

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Appendices

Assessment of the likelihood of success of particular adaptation actions in each climatic domain

With each management option, an assessment has been made of the evidence for its likelihood of success in specific regions (B: boreal, Te: Temperate, S: Subtropical and Tr: Tropical). The classification follows the IPCC principles for assessing qualitative information namely, A: much evidence, much agreement; B: little evidence, much agreement; C: much evidence, little agreement; and D: little evidence, little agreement. Care should be taken in interpreting these, as the forests in these broad regions can differ significantly, as can the likelihood of particular impacts. In addition, the available evidence that particular strategies will be successful is very limited, as few properly controlled long-term experiments on the interaction between forests and climate change have been conducted. Instead, these assessments are based on the expert opinion of the authors of the likely impacts of particular management options.

Appendix 6.1 Potential strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining (or increasing) forest area.

Impact	S/O	Adaptation option	B	Te	S	Tr
Conversion of forest to energy plantations	S	Establish policies to limit conversion of existing forest to non-woody energy plantations	C	C	C	C
Deforestation and forest degradation	S	Provide alternative coping mechanisms for vulnerable communities that would otherwise use forests when facing crop and livestock failures	B	B	A	A
		Increase forest law enforcement in areas impacted by illegal logging	B	B	A	A
		Ensure the proper functioning of community governance and equitable sharing of benefits among individual families	B	B	A	A
		Generate means to provide private owners with economic flexibility if they choose to use their land for forestry (similar to the economic flexibility associated with raising livestock)	A	A	A	A
		Enhance local welfare through the promotion of community-based forest management and restoration, the development of agroforestry, the availability of microfinance, training in NWFP management, manufacturing and marketing, and a greater role for women	A	A	A	A
		Improve community and individual welfare through community plantings, village woodlots, shelterbelts, partnerships with private sector and public-awareness campaigns through the media, children's education programmes and field demonstrations	B	B	A	A
		Design and implement REDD mechanisms that allow for a flow of capital to those forest users that decide in favour of sustainable forest use, rather than non-forest use of forest lands	D	D	D	D
		Support efforts to improve welfare through sound governance, strengthening institutions, greater participation and education, greater accountability, reinforced monitoring and community access to benefits	A	A	A	A
Use of wood for domestic energy	O	Substitution of firewood used far from its source by more energy-efficient fuels (e.g. charcoal)	B	B	A	A
		Substitution of firewood and charcoal by renewable energy sources	C	C	B	A

Sources for the adaptation options: FAO 2008.

Appendix 6.2 Potential strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of conserving biological diversity of forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Alteration of plant and animal distribution	S	Minimize fragmentation of habitat and maintain connectivity	D	A	A	A
		Reduce deforested areas to above threshold values (30–40%)	D	A	A	A
		Maintain representative forest types across environmental gradients in reserves	B	B	B	B
		Protect primary forests	A	A	A	A
		Protect climate refugia at multiple scales	B	B	B	B
		Identify and protect functional groups and keystone species	B	B	B	B
		Strategically increase size and number of protected areas, especially in 'high-value' areas	B	B	B	B
		Provide buffer zones for adjustment of reserve boundaries	B	A	A	B
		Protect most highly threatened species ex situ	A	A	A	A
		Develop a gene management programme to maintain diverse gene pools	B	B	B	B
		Ensure that conservation corridors extend across environmental gradients	B	B	B	B
		Ensure that infrastructure investments do not interrupt conservation or riparian corridors	D	D	D	D
		Create artificial reserves or arboreta to preserve rare species	B	B	B	B
		Increased regional cooperation in species management and protected areas management	A	A	A	A
	O	Practice low-intensity forestry and prevent conversion to plantations	D	B	A	A
		Assist changes in the distribution of species by introducing them to new areas; establish 'neo-native forests'	B	B	B	B
		Increase the colonizing capacity in the areas between existing habitat and areas of potential new habitat	A	A	A	A
		Design tree plantations to have a diverse understory	D	D	B	B
		For planted forests, establish indigenous, mixed-species stands, maximize natural genetic diversity, mimic the structural properties of the surrounding forests and avoid direct replacement of native ecosystems	A	A	A	A

Impact	**S/O**	**Adaptation Options**	**B**	**Te**	**S**	**Tr**
Changes in the fre-quency and severity of forest disturbance	S	Maintain natural fire regimes	A	A	B	B
		Reduce the rate of deforestation and forest degradation	D	A	A	A
		Maintain under and above-ground seed sources (seed banks or trees)	B	B	B	B
	O	Allow forests to regenerate naturally following disturbance; prefer natural regeneration wherever appropriate	D	D	D	D
		Reduce fire hazard by implementing reduced impact logging, especially a reduction in the size of felling gaps and fuel loads	B	B	A	A
Habitat in-vasions by non- native species or by native species not considered native to this area	O	Control invasive species	A	A	B	B

Sources for the adaptation options: Aragão et al. 2008, Barlow and Peres 2008, Betts et al. 2008a, Biringer et al. 2005, Blate 2005, Carey 2003, Drever et al. 2006, Guariguata et al. 2008, Hannah et al. 2002, Holdsworth and Uhl 1997, Holling 2001, Kellomaki et al. 2005, Killeen and Solórzano 2008, Ledig and Kitzmiller 1992, Loope and Giambelluca 1998, Noss 2001; Parker et al. 2000, Persuy 2006, Peters 1990, Vos et al. 2008.

Appendix 6.3 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining the health and vitality of forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Increased frequency and severity of forest pestilence	S	Adjust harvest schedules to harvest stands most vulnerable to insect outbreaks	B	B	B	D
		Improve governance of frontier forest areas to reduce the risk of fires associated with settlement	D	–	B	B
	O	Plant genotypes tolerant of drought, insects and/or disease	B	A	A	A
		Reduce disease losses through sanitation cuts	A	A	A	A
		Breed for pest resistance and for a wider tolerance to a range of climate stresses and extremes	D	B	B	D
		Used prescribed burning to reduce fire risk and reduce forest vulnerability to insect outbreaks	B	B	B	D
		Employ silvicultural techniques to promote forest productivity and increase stand vigour	C	C	C	B
		Shorten the rotation length to decrease the period of stand vulnerability to damaging insects and diseases and to facilitate change to more suitable species	B	B	B	B
		Increase the genetic diversity of trees used in plantations	B	B	A	A
		Establish landscape-level targets of structural or age-class, of landscape connectivity for species movement, and of passive or active measures to minimize the potential impacts of fire, insects and diseases	B	B	B	B
Increased mortality due to climate stresses	S	Avoid planting new forests in area likely to be subject to natural disturbances (e.g. floods)	C	C	C	C
	O	Minimize amount of edge created by human disturbances	D	D	D	A
		In natural forests, conduct thinning to stimulate crown development and eventual fruiting of seed trees	–	–	B	A
		In natural forests, create canopy or ground disturbances to assist the regeneration of light-demanding species	–	–	A	A
		Maximise number of seed trees retained when harvesting natural forest	–	–	A	A
		For dioecious species in natural forests, retain similar numbers of adult male and female trees to ensure reproduction and maintain genetically effective population sizes	–	–	A	A

Impact	S/O	Adaptation Options	B	Te	S	Tr
Decreased health and vitality of forest eco-systems due to cumulative impacts of multiple stressors	S	Reduce non-climatic stresses, especially air pollution, to enhance ability of ecosystems to respond to climate change	A	A	A	A
		Restore degraded areas to maintain genetic diversity and promote ecosystem health	A	A	A	A
		Conduct monitoring at sub-national and national scales of all forests (not just production forests) through improved national, regional or operational forest health monitoring networks, har-monization of inventory and reporting protocols of such networks and expanding and linking invasive species networks	A	A	A	A
		Pursue better and more cost-efficient methods of multi-scale monitoring systems for early detection of change in forest status and health	A	A	A	A
		Develop, test and improve risk assessment methods	B	B	B	B
		In natural forests, ensure high juvenile population sizes and thus promote high genetic variation	B	B	B	B
		Reduce mortality by reducing the frequency of lianas	–	–	–	A
		Encourage transfer of resources (financial and knowledge) from developed to developing and least-developed countries and build capacity where needed	A	A	A	A

Sources for adaptation options: Ahmed et al. 1999, Battisti et al. 2000, Biringer 2003, Bouget and Duelli 2004, Burdon 2001, Chapin et al. 2007, Coops et al. 2008, Cornelius and Watt 2003, Coyle 2002, Dale et al. 2001, De Dios et al. 2007, De Moraes et al. 2004, Dickmann 2006, Dodds et al. 2007, FAO 2008, Farnum 1992, Foster and Orwig 2006, Fredericksen and Pariona 2002, Friedenberg et al. 2007, Guariguata and Sáenz 2002, Guariguata et al. 2008, Gottschalk 1995, Grogan and Galvão 2006, Grogan et al. 2005, Hurley et al. 2007, Jacobs 2007, Kellomaki et al. 2005, Kizlinski et al. 2002, Koski and Rousi 2005, Laurance 2004, Laurance and Fearnside 2002, Lemmen and Warren 2004, Liebhold et al. 1998, Lindner et al. 2000, Lombardero et al. 2008, Mason and Wickman 1991, Meentemeyer et al. 2008, Moreau et al. 2006, Namkoong 1984, Negron and Popp 2004, Ofori, and Cobbinah 2007, Oliva and Colinas 2007, Opuni-Frimpong et al. 2008, Phillips et al. 2005, Piirto and Valkonen 2005, Schmidt 2003, Schroeder 2007, Sizer and Tanner 1999, Smith et al. 1997, Snook and Negreros-Castillo 2004, Steinbauer et al. 2006, Stone 2001, Turchetti et al. 2008, Tuskan 1998, van Staden et al. 2004, Volney et al. 1999, Wallin et al. 2008, Wang et al. 1995, Wargo and Harrington 1991, Waring and O'hara 2005, Yanchuk et al. 2006, Yanchuk et al. 2008, Yeh 2000, Ylioja et al. 2005, Zanuncio et al. 2001, Zas et al. 2006.

Appendix 6.4 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining the productive capacity of forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in the frequency and severity of forest disturbance	S	Practice high-intensity plantation forestry in areas managed for timber production where an increase in disturbance is anticipated	C	C	C	C
	O	Assist in tree regeneration	B	A	A	A
		Maintain seed banks (in soil or trees)	A	A	A	B
		Actively manage forest pests	A	A	A	A
		Increase the stability of stands through increasing species and structural diversity, de-emphasizing means to enhance or maintain short-term productivity	D	B	D	D
		In drought-prone areas, increase the use of pre-commercial and commercial thinning to enhance the tolerance of the remaining trees and introduce drought-resistant species where appropriate	B	B	B	B
		Preferentially use coastal provenances of species in areas likely to be affected by increased windstorms	–	B	B	B
Changes in forest growth	O	Practice high-intensity forestry in areas managed for timber production to promote growth of commercial tree species	C	B	B	C
		Include climate variables in growth and yield models	A	A	A	A
		Enhance forest growth through forest fertilization	C	C	C	C
		Employ vegetation control techniques to offset drought	C	C	B	B
		Pre-commercial thinning or selective removal of suppressed, damaged or poor quality individuals	B	A	A	A
		Identify more suitable genotypes	A	A	B	B
		Plant genetically modified species	D	D	D	D
		Match provenances to new site conditions	A	A	A	B
		Adjust the annual cut to maintain the forest processes in as close an equilibrium state as possible	A	A	A	B
Increased nitrogen losses	O	Use nitrogen fertilization or encourage N-fixing species in the understory	C	C	C	D

Impact	S/O	Adaptation Options	B	Te	S	Tr
Species are no longer suited to site conditions	O	Underplant with other species or genotypes where the current advanced regeneration is unacceptable as a source for the future forest	D	B	B	B
		Design and establish long-term multi species/seedlot trials to test improved genotypes across a diverse array of climatic and latitudinal environments	A	A	B	B
		Reduce the rotation cycle to speed the establishment of better adapted forest types	C	A	A	D
		Relax any rules governing the movement of seed stocks from one area to another; examine options for modifying seed transfer limits and systems	C	B	A	B
		Use germplasm mixtures with high levels of genetic variation when planting	B	B	B	B
		In plantations, avoid the use of clonal material selected purely on the basis of past growth rates	B	A	B	B
Invasions by non-native species or by native species not considered native to the area	O	Control those undesirable plant species that will become more competitive with harvestable species in a changed climate	B	A	A	B

Sources for adaptation options: Bastien et al. 2000, BCMOF 2006a, Biringer 2003, FAO 2008, Fredericksen and Putz 2003, Garcia-Gonzalo et al. 2007, Guariguata et al. 2008, Gitay et al. 2001, Innes and Nitschke 2005, IPCC 2000, Kellomaki et al. 2005, Kelty 2006, Lamb et al. 2005, Ledig and Kitzmiller 1992, Lemmen and Warren 2004, Lindner et al. 2000, Papadopol 2000, Parker et al. 2000, Peña-Claros et al. 2007, 2008, Petit and Montagnini 2006, Piermont 2007, Sáenz-Romero et al. 2006, Smith et al. 1997, Schulze 2008, Spittlehouse and Stewart 2003, Villegas et al. 2008.

Appendix 6.5 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining and enhancing long-term multiple tangible socioeconomic benefits in forests. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in tree cover	O	Substitution of wood by other fuels for cooking and heating	A	A	A	A
Changes in socioeconomic resilience	S	Anticipate variability and change and conduct vulnerability assessments at a regional scale	A	A	A	B
		Enhance capacity to undertake integrated assessments of system vulnerabilities at various scales	A	A	A	B
		Diversify forest economy (e.g. dead wood product markets, value added products, non-timber forest products)	A	A	A	A
		Diversify regional economy (non-forest based)	A	A	A	B
		Develop technology to use altered wood quality and tree species composition, modify wood processing technology	A	A	B	B
		Make choice about the preferred tree species composition for the future; establish objectives for the future forest under climate change	B	B	B	B
		Increase extension activities in areas subject to high levels of migration and family turnover	A	A	B	B
		Enhance dialogue amongst stakeholder groups to establish priorities for action on climate-change adaptation in the forest sector	A	A	B	B
	O	Conduct assessments in local communities to determine priorities and preferences	B	B	B	B
		Strengthen local organizational and planning skills	B	B	B	B
		Compilation of local and community knowledge about past and current changes	B	B	B	B

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in frequency and severity of forest disturbance	S	Include risk management in management rules and forest plans and develop an enhanced capacity for risk management	A	A	B	B
		Conduct an assessment of greenhouse-gas emissions produced by internal operations	A	A	B	B
		Increase awareness about the potential impact of climate change on the fire regime and encourage proactive actions in regard to fuels management and community protection	A	A	B	B
		Encourage appropriate capital investments, re-training of work-force and mobility of the population	A	A	B	B
	O	Protect higher value areas from fire through better fire management planning and precautions ('firesmart' techniques)	A	A	A	B
		Increase amount of timber from salvage logging of fire or insect disturbed stands	A	A	A	B
Changes in demand for nature-based tourism and recreational services	O	Gather information about natural and cultural heritage values and ensure that this knowledge is used as part of the decision-making process established to manage for climate-change impacts.	A	A	B	B
		Establish on-site management programmes designed to plan ecologically, manage carbon sinks, reduce greenhouse-gas emissions, and develop tools and techniques that help mitigate the impacts of rapid climate change	A	A	C	C
		Expand tourism and recreational services to 3 or 4 season operations	A	A	B	–

Sources for adaptation options: BCMOF 2006a, Brondizio and Moran 2008, Chapin et al. 2004, FAO 2008, Johnston et al. 2006, Kellomaki et al. 2005, Keskitalo 2008, Lemmen and Warren 2004, Ogden 2007, Ogden and Innes 2008, Ohlson et al. 2005, Spittlehouse 2005, Spittlehouse and Stewart 2003.

Appendix 6.6 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of conserving and maintaining the soil and water resources in forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Increased soil erosion	O	Maintain, decommission and rehabilitate roads to minimize sediment runoff due to increased precipitation and melting of permafrost	A	B	A	A
		Minimize soil disturbance through low-impact harvesting activities	A	A	A	A
		Minimize density of permanent road network and decommission and rehabilitate roads to maximize productive forest area	A	A	B	B
		Limit harvesting operations to the appropriate seasons to minimize road construction and soil disturbance	A	A	A	A
		Change road and ski track specifications to anticipate higher frequency of intense rainfall events	B	B	B	A
Increased terrain instability	S	Avoid constructing roads in landslide-prone terrain	A	A	A	A
Changes in the timing of peak flow and volume in streams	O	Examine the suitability of current road construction standards and stream crossings to ensure they adequately mitigate the potential impacts on infrastructure, fish and potable water	A	A	A	A
Changes in the salinity of coastal forest ecosystems	S	Avoid low river flows, especially from up-stream abstraction	B	B	A	A

Sources for adaptation options: BCMOF 2006a, IPCC 2000, Mote et al. 2003, Spittlehouse and Stewart 2003.

Appendix 6.7 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining forest contributions to global carbon cycles. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Alteration of forest sinks and increased CO_2 emissions from forested ecosystems	S	Mitigate climate change through forest carbon management	B	B	B	B
		Increase forested area through afforestation and reforestation of degraded forest land	A	A	B	B
		Include both emissions from and sequestration to forests in all national and global accounting of carbon stocks and changes in carbon stocks	B	B	B	B
		Reduce forest degradation and avoid deforestation	A	B	A	A
		Combine existing areas of multi-functional forests and reserves with afforestation with short-rotation coppice for bioenergy production	B	A	D	D
	O	Enhance forest growth and carbon sequestration through forest fertilization	B	C	D	B
		Modify thinning practices (timing, intensity) and rotation length to increase growth and turnover of carbon	A	A	D	B
		Minimize density of permanent road network and decommission and rehabilitate roads to maximize forest sinks	–	–	D	B
		Decrease impact of natural disturbances on carbon stocks by managing fire and forest pests	A	A	B	B
		Minimize soil disturbance through low-impact harvesting activities	A	A	B	A
		Enhance forest recovery after disturbance	B	B	B	B
		Increase the use of forests for biomass energy	A	A	C	C
		Practice low-intensity forestry and prevent conversion to plantations	B	B	D	B

Sources for adaptation options: BCMOF 2006a, FAO 2008, Garcia-Quijano et al. 2008, IPCC 2000, Kellomaki et al. 2005, Lemmen and Warren 2004, Nabuurs et al. 2008, Noss 2001, Parker et al. 2000, Spittlehouse 2005, Spittlehouse and Stewart 2003, Wheaton 2001, White and Kurz 2003.

Appendix 6.8 Potential strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining the health of people in forest-dependent communities. (Adapted from Colfer 2008a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Deteriorating health of forest-dependent peoples	S	Promote research on various aspects of forest foods	D	C	A	A
		Promote research on smoke inhalation	D	C	A	A
		Promote research on forest dwellers, their ill-health and their relationship to their environment	D	D	B	B
		Undertake systematic, comparative, longitudinal, holistic interdisciplinary studies on health and forests	B	B	B	B
		Promote research on the safety, efficacy and quality of medicinal plants	D	D	A	A
		Promote research on gender differences in health	D	C	C	C
		Recognize and address the interactions among environment, population, health, income generation, education and women's status	C	C	C	C
		Promote greater interaction/cooperation between environment and health sectors	A	A	A	A
		Promote interdisciplinary cooperation in health and forest interactions	A	A	A	A
		Develop better integration between traditional and modern health sectors	D	C	A	A

Impact	S/O	Adaptation Options	B	Te	S	Tr
	O	Dispense better education/information relating to health and use of traditional forest medicines	D	D	C	C
		Encourage policy changes that recognize the value of medicinal plants and integrate them with formal health-care systems	D	D	C	C
		Investigate and select appropriate certification and marketing networks for medicinal plants and producers	D	D	C	C
		Improve combined treatment and prevention	A	A	A	A
		Encourage the conservation and sustainable use of forest foods and medicines	A	C	A	A
		Develop new social understanding, new technology, new organizational approaches to prevent illness connected with smoke inhalation	D	C	A	A
		Enable greater accessibility to family planning in forested areas, for both human and forest well-being	D	C	C	C
		Reduce human contact with vectors, and improve disease recognition, epidemiology and biosecurity	D	B	B	B
		Encourage greater involvement of forest sector in sustainable forest management to benefit human health	D	A	D	D
		Develop closer, more effective partnerships between conservation and health professionals	D	C	D	D

Sources for adaptation options: Ali 2008, Allotey et al. 2008, Butler 2008, Colfer et al. 2006, 2008b, Cunningham et al. 2008, Dounias and Colfer 2008, Epstein 1994, Fowler 2008, Gonzalez et al. 2008, Kwa 2008, Lopez 2008, Pattanayak and Yasuoka 2008, Persoon 2008, Smith 2008, Vinceti et al. 2008.

Appendix 6.9 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining and enhancing long-term multiple intangible socioeconomic benefits to meet the needs of societies. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in socio-economic resilience	S	Anticipate variability and change and conduct vulnerability assessments at a regional scale	A	A	A	A
		Enhance capacity to undertake integrated assessments of system vulnerabilities at various scales	B	B	B	B
		Foster learning and innovation and conduct research to determine when and where to implement adaptive responses	B	B	B	B
		Review forest policies, forest planning, forest-management approaches and institutions to assess our ability to achieve social objectives under climate change; encourage societal adaptation (e.g. forest policies to encourages adaptation, revision of conservation objectives, changes in expectations)	A	A	A	A
Erosion of local forest-related knowledge in forest-dependent societies	S	Support indigenous and local community efforts to document and preserve local forest-related knowledge and practices for coping with climatic variability and associated changes in forest structure and function	A	A	A	A
		Incorporate study of local forest-related knowledge into forestry and environmental education	C	C	C	C
		Promote research examining the underlying ecological bases of traditional forest and agro-forest management practices	C	C	C	C
		Encourage multidisciplinary, participatory research and dialogue between forest scientists and holders/users of local forest knowledge aimed at increasing adaptive capacity of both local and formal science-based approaches to sustainable forest management	C	C	C	C

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in the frequency and severity of forest disturbance	S	Include risk management in management rules and forest plans and develop an enhanced capacity for risk management	B	B	B	B
		Increase awareness about the potential impact of climate change on the fire regime and encourage proactive actions in regard to fuels management and community protection	A	A	A	A
Human/ wildlife conflicts	S	Establish new mechanisms to enable the more peaceful co-existence of wildlife and people	D	D	D	D
Crop failure in climatically marginal agricultural areas	S	Reliance on forest products as a buffer to climate-induced crop failures	–	A	A	–
		Decentralization of local governance of resources i.e. the Community Based Natural Resource Management (CB-NRM) approach to promote use of ecosystems goods and services as opposed to reliance on agriculture	–	A	B	–

Sources for adaptation options: Agnoletti 2007, Berkes et al. 2000, BCMOF 2006a, Chapin et al. 2004, FAO 2008, Johnston et al. 2006, Kellomaki et al. 2005, Ohlson et al. 2005, Parrotta et al. 2008, Ramakrishnan 2007, Spittlehouse 2005, Spittlehouse and Stewart 2003.