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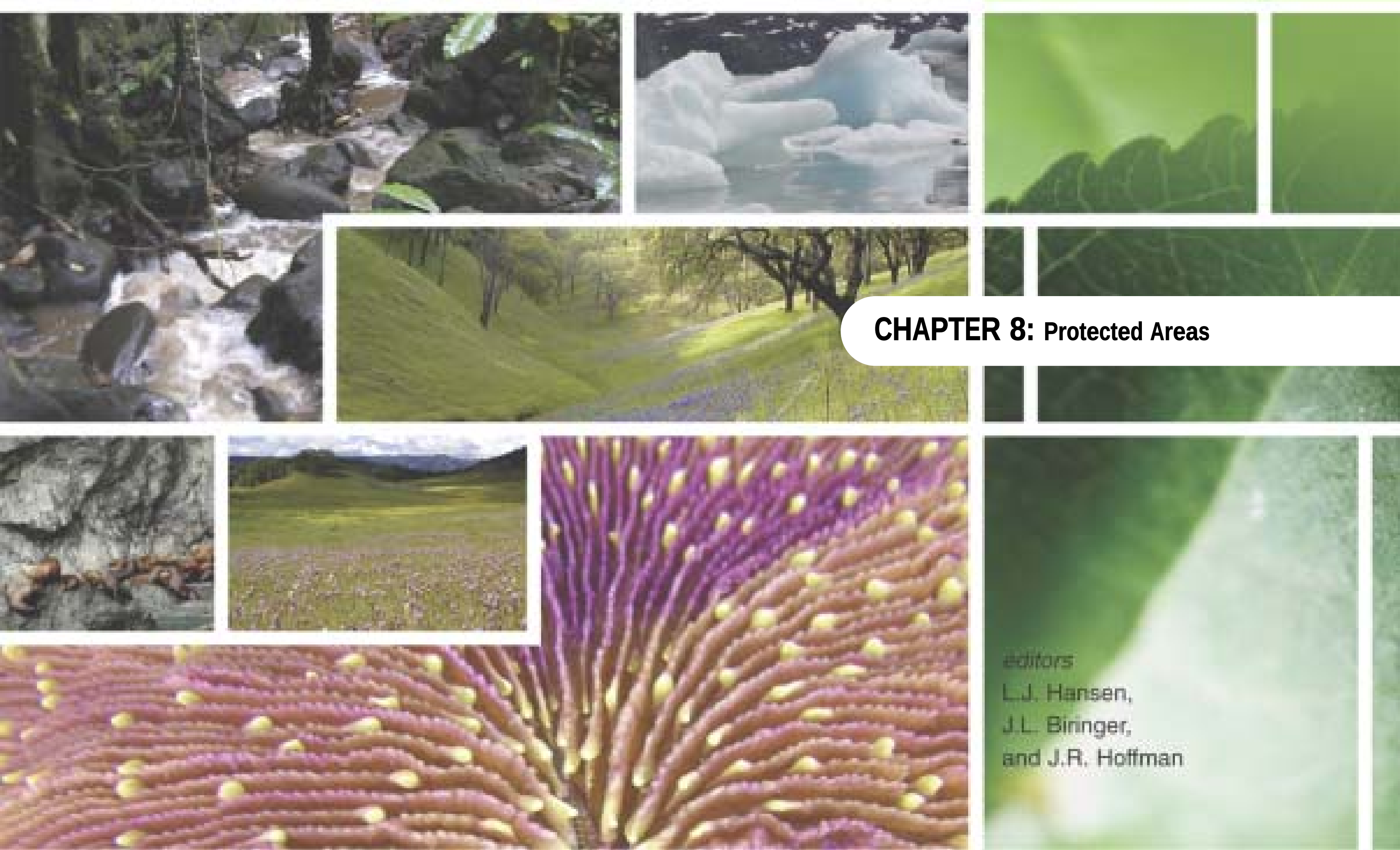
BUYING TIME:

A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems



CHAPTER 8: Protected Areas

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Ecological and Socio-economic Benefits of Protected Areas in Dealing with Climate Change

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Equilibrium

WELL-DESIGNED AND MANAGED protected areas may ameliorate some of the problems caused by climate change, with benefits well beyond the park boundaries. These potential benefits are predicated on a number of assumptions about the way in which natural ecosystems will respond to changing climate—some of which still need to be thoroughly tested—and on further assumptions about the design and management of protected area systems. But we already know enough about the predicted and observed impacts of climate change, and about the role of protected areas, to draw some initial conclusions about how to get the best out of protected area networks in terms of buffering against climate change.

This chapter outlines some of the known and expected benefits that protected areas offer national or regional strategies to increase resilience against climate change and suggests ways in which protected area authorities and managers can maximise these benefits. Given the uncertainty inherent in climate models, this advice is still preliminary. Most contemporary research on the links between climate change and protected areas not surprisingly focuses on the threats posed to parks and reserves. Their potential role in buffering ecosystems and human societies has been less carefully studied and at least some of the claims that have gained attention are based more on hearsay and received wisdom than on quantitative data or real-life examples. Information has often not progressed from hurriedly prepared technical reports into the scientific literature, making judgements more difficult. In the following account we try to sort out the myths from the reality and to provide protected area managers with a guide to maximizing the potential benefits that protected areas can offer in efforts to resist the impacts of climate change.

There is a growing recognition that natural ecosystems, both large and small, could provide a suite of ecosystem services related to climate change, ranging from protection against immediate physical impacts such as rising temperatures, unstable climates and rising seas, to providing additional insurance against the predicted instability of agriculture, fisheries and water resources. We look first at the significance of particular impacts and then at how protected areas might relieve symptoms, in each case referring to real-life examples of protected areas. Wherever possible, we have drawn on protected area management interventions that have been developed specifically as a response to climate change; in one or two cases we use examples which have relevance to climate change but that have been initiated for other reasons.

The main issues examined are: disaster mitigation covering hurricanes, droughts, flooding, avalanches and coastal erosion; fires; biodiversity; water security particularly with respect to drinking water; the need for rapid crop adaptation; and food security, including the potential of crop and fish stock failure. In some cases, the role of protected areas in mitigating or relieving effects is already clear, while in others the jury is still out and we need to learn more before management recommendations can achieve any degree of certainty.

Managing to Relieve the Impacts of Climate Change

Many protected area managers already wrestle with a range of problems relating to climate change effects within their parks or reserves. Here we suggest that carefully designed and managed protected areas can help relieve problems *beyond* the park boundary. In some cases protected areas are simultaneously a potential buffer against a particular climate-related problem and at risk from the same problem, creating a tension and the need for some tough decisions from managers. We have already made clear that there is a lot to learn about many of these impacts and therefore research and monitoring must be important components of any response. In addition, opportunities to use protected areas as buffers against climate change require two additional management responses:

PLANNING TO MAXIMIZE THE BENEFITS OF PROTECTED AREAS IN RELIEVING THE SYMPTOMS OF CLIMATE CHANGE: the importance of assessing protected area management effectiveness is increasingly recognized; adding climate change elements into such assessments would be relatively easy and enhance their usefulness dramatically. This

Figure 1: Possible matrix for conducting a local overview of climate change effects

Issue	Current situation regarding the issue	Value of PA in addressing threat (descriptive or quantitative)	Trend under climate change	Site modification to maximise benefits	System modification to maximise benefits	Potential economic value
Disaster mitigation						
Fire						
Biodiversity conservation						
Food security						
Water security						

could be helpful for individual protected areas and, in the case of a system assessment, aid in planning future protected areas. Such assessments could include primary research or a thorough literature review, or begin more simply, with a local survey to overview the situation. A draft set of questions for such an overview is suggested in Figure 1.

Ideally, such an analysis could be carried out on the system level (ecosystem or landscape), so that both protected area agencies and individual managers can put management actions into a national or regional context.

TESTING HYPOTHESES THAT PROTECTED AREAS CAN HELP MITIGATE THE EFFECTS OF CLIMATE CHANGE: the cases described below show managers already thinking about using land and water resources to buffer against climate change (or sometimes making interventions that could help mitigate climate change without recognizing the connection). However, these are rare examples. More systematic work is needed to quantify beneficial impacts and to refine management interventions to maximize these benefits.

In the following sections, we review the evidence, suggest what protected areas can do and, in each case, provide at the end a brief summary of management responses.

DISASTERS: DROUGHTS, FLOODS, AVALANCHES AND COASTAL EROSION

Like the four horsemen of the apocalypse, a whole suite of disasters are predicted to increase in severity and frequency as a result of changing climate: changing rainfall patterns causing floods and droughts; extreme weather events such as hurricanes; a combination of climate changes that could increase avalanches; and the inexorable rise in sea level along with increased storm damage to coasts. Available evidence, from modeling studies and observations, supports some but not all of these popular predictions. The Intergovernmental Panel on Climate Change (IPCC) concludes that rainfall scenarios suggest an increase in both flooding and drought frequency in many parts of the world (McCarthy et al., 2001), and these predictions are echoed by both the United Nations (United Nations World Water Assessment Programme, 2001) and the World Bank (World Bank, undated), while the impacts of climate change on frequency and intensity of hurricanes remain more uncertain. Variations in annual temperatures may not increase total avalanches, but certainly make it more difficult to predict when and where they will occur. Sea level rise is predicted to have enormous impacts on many low-lying coastal communities; as this chapter is written the government of the Pacific island nation of Tuvalu is lobbying the Australian government for space for the country's 9,300 inhabitants, currently living on land only 3 metres above the sea and considering a mass evacuation (Fickling, 2003).

FLOOD

The presence of natural vegetation generally reduces storm-related erosion and landslip/landslide and can ameliorate local flooding, but is normally not enough to stop major floods. Research in New Zealand after Hurricane Bola in 1988 found that shallow landslips/landslides only occurred in 1% of the area with forests older than 5 years versus 30% of the area of cleared lands (Trustrum and Page, 1992). However, a review carried out for the UN Food and Agriculture Organisation concluded that forests were only likely to reduce flooding in relatively minor storms (Calder, 2000), and claims that deforestation in the Himalaya has led to flooding in the Ganges are now believed to be incorrect (Hamilton, 1987). A widespread belief that Hurricane Mitch in Central America had less impact on areas still rich in natural forest, such as Nicaragua, has been challenged by the Center for International Forestry Research (Kaimowitz, 2002). Yet in other cases, forests do appear to have an important role to play in regulating water flow, including particularly swamp forests such as the huge Varzea forests in the Amazon. Forests also provide benefits at a smaller scale, in the areas immediately surrounding the forest, so that integration of protected forests with working landscapes, as in IUCN Category V protected areas, offers benefits to local communities. A review in North America concluded that for many reasons, including likely temperature changes and more frequent and intense storm events, climate change increased the need for forest protected areas to be as large as possible, including the ability to withstand extreme weather events (Noss, 2001).

DROUGHT

Maintaining natural vegetation can provide an important insurance policy in areas prone to drought and there is a growing consensus that social impacts of drought in the Horn of Africa have been exacerbated by prior forest loss. In arid Djibouti, the Foret du Day National Park is the only large protected area in the country (IUCN category II, 10,000 ha) and is also the only significant forest area. Being at a higher elevation and subject to mists, it retains more vegetation and thus provides a source of forage during drought: the protected area is thus a natural buffer against starvation. Currently traditional management patterns are breaking down and over-grazing is resulting in replacement with drought resistant trees, pointing to the need for negotiation and changes in management (Barrow, pers. comm.).

AVALANCHE

At a smaller scale, protection zones, which may or may not be officially protected areas but fulfill the same functions, are a key feature in avalanche control and small-scale flood control throughout the mountainous areas of Europe. Forest management in the Tatra National Park, a transboundary protected area between Poland and Slovakia, has long emphasised avalanche control. In the Swiss national forest, 8% of the total area is managed primarily for avalanche protection and as long ago as the late 1980’s this was calculated to have an annual value of 3-4 billion Swiss francs (Küchli et al., 1998).

COASTAL IMPACTS

Protected areas play an even clearer role in disaster mitigation in marine and coastal areas. Sea level rise and increased storm damage puts coastal communities and small islands at particular risk. Building physical barriers against the rising sea is technically difficult and colossally expensive for countries with large, low-lying coastal regions, stimulating a new approach to integrated management, relying on natural features such as coral reefs and mangroves. A comprehensive review of marine ecosystem services suggests that natural features like coral reefs and mangroves are the most cost-effective option for maintaining coastal integrity and cannot easily be substituted by artificial reefs and seawalls or by aquaculture (Moberg and Rönnbäck, 2003)—making responses such as restoration of mangroves even more important (Field, 1999).

Paradoxically, these natural features are also amongst those most acutely at threat from climate change. In these cases, managers will be faced with a series of hard decisions, balancing the benefits from a feature like a reef or mangrove, the chances of it surviving climate change and the costs and benefits of protection. In some cases trade-offs may be necessary. For example choosing to concentrate money and resources into key areas and abandoning others. Looking beyond spatial biodiversity conservation to include other factors, including the wider benefits of protected areas in terms of coastal protection, may influence the choice of where to focus the most effort and could also help attract additional support for those protected areas that are also helping to mitigate climate change impacts.

The Sundarbans region of Bangladesh provides an almost text book example of the link between climate change and protected areas. This huge area of mangrove in the Ganges floodplain is both at risk from climate change impacts and a potential tool in resisting the impacts of such change. A recent review summarised seven national and international analyses of climate change impacts on Bangladesh (Huq et al., 2003) and concluded that the Sundarbans were at risk and increased disasters were likely in the coastal zones covering 30% of the country. Impacts would result from sea-level rise and associated factors including high evapotranspiration and low flow in winter resulting in increased soil salinity. The IPCC predicts that in worse case scenarios up to 75% of the mangroves could disappear.

The area is heavily affected by tropical storms: about 10% of the world's tropical cyclones occur in the Bay of Bengal and of those 17% hit land in Bangladesh. The mangroves fringing the delta have been a traditional barrier, providing socially and economically valuable services. The Southwest Area Water Resources Management Project calculated that the absence of the Sunderbans mangroves would mean building 2,200 kilometres of cyclone/flood embankments requiring a capital investment of Taka 16 billion (US$ 294 million) with a yearly maintenance budget of Taka 320 million (US$ 6 million) (UNDP et al., 1995). The Sundarbans are protected in three connected wildlife sanctuaries (IUCN category IV), although they continue to be degraded and in the past have been heavily logged (Scott, 1989). This has led to a requirement for mangrove restoration, and some experience is already being developed in the Sundarbans, for example on Sagar Island (Saha and Choudhury, 1996).

Coral reefs also provide barriers to wave activity for low-lying coastal regions and islands but, like mangroves, are themselves one of the first habitats to suffer the impacts of climate change, mainly through coral bleaching. Many coral communities are also suffering intense damage from, over-exploitation, shipping and pollution. Marine protected areas can relieve some pressure from corals, thus giving them the best chance of maintaining themselves and thus also providing a protective function. In American

Samoa WWF scientists are working with local communities to look at options for managing change. They are examining options for reducing the impact of coral bleaching in the National Park of American Samoa and Fagatele National Marine Sanctuary by, for example controlling high nutrient terrestrial run-off into coastal waters.

FIRE

Climate change will add an additional element to the already complex relationship between fires and natural ecosystems. Hotter, drier conditions tend to increase fire frequency, resulting in changes in vegetation as more fire-tolerant species become common in both the tropics (Goldamer and Price, 1998) and in temperate and boreal regions: in northern Minnesota, USA, forest fires were most common in the warm, dry periods of the fifteenth and sixteenth centuries (Clark, 1988) and research in Canada suggests that a doubling of atmospheric CO_2 could lead to a 46% increase in seasonal severity rating for forest fires, and possibly a similar increase for their incidence (Flannigan and Van Wagner, 1991).

In areas where fires have recently burned at unnatural and ecologically damaging levels – particularly in tropical forests where under normal conditions fires are a rarity – there is strong evidence of a link with the climate phenomenon called ENSO (El Niño-Southern Oscillation), which causes periodic droughts (Leighton and Wirawan, 1986), including the drought that affected much of the forests which caught fire in 1997 and 1998. The frequency and intensity of El Niño could itself be increasing as a result of climate change (Trenberth and Hoar, 1996, 1997), which means the world faces warmer, more violent weather, and more forest fires. More generally, increased droughts and average temperatures in fire prone areas may also increase the frequency of fires. However, these impacts are likely to be outweighed by the influences of management: the fires in Brazil and Indonesia in 1997 and 1998 may have been intensified because of El Niño, but they were begun by plantation owners and slash and burn farmers (Holdsworth and Uhl, 1997) and conditions were made more suitable for fire through earlier management changes (Uhl et al., 1988).

Forest fires can directly affect protected areas – for example Kutai National Park in Borneo was virtually destroyed by fire (Goldammer and Seibert, 1992) – but in other parts of the world unnatural levels of fire suppression are a significant conservation problem (Noss et al., 1995) and it therefore follows that fire management responses to climate change must be tailored to local conditions.

In areas where fire is an expected part of the ecosystem, some balance between management and non-intervention will probably be optimal, with prescribed burning usually a more successful management intervention than outright suppression (Stephenson, 1999) (which allows build-up of fuel and less frequent, but more catastrophic, fires). In fire-dominant landscapes, leaving forests to attain old-growth status can increase the risk of fire and thus protected areas close to centers of population are sometimes regarded as an added fire hazard. In the aftermath of unusually intense fires in Australia in

February 2003, there were calls from some quarters for logging in national parks to reduce fire risk (Victoria Parks Service, pers. comm.) and some measure of fire management may be necessary. Conversely, in areas where fire is generally a factor of human intervention, such as in tropical moist forests, frequent forest fires cause long-term damage (Woods, 1989) and protected areas can provide important buffers to prevent the further spread of fires from poorly managed swidden agriculture or fires used in pasture creation or clearance for plantations.

Training in community fire management is in these cases an important part of management in those protected areas with resident human communities (Karki, 2002). For example, working with local communities to manage and reduce fires is a major focus of management for the Pha Taem protected areas complex between Thailand, Laos and Cambodia, and the presence of the protected area has opened up the possibility of cross-border cooperation in a way that would not otherwise be possible (Trisurat, 2003). In other protected areas with grassland or savannah habitats, such as the Serengeti in Tanzania, controlled use of fire is an integral part of management, usually to maintain particular ecosystems.

Biodiversity

Ever since Edward Wilson published his classic text on biodiversity (Wilson, 1988), it has been recognized that we are undergoing rapid loss of species and it has long been argued that climate change will increase this trend (Markham, 1996). Recent studies suggest that a significant impact of global warming is already discernible in plant and animal species (Root et al., 2003). Researchers have also found that other factors such as the presence of invasive species and imbalances in hydrological cycles increase these threats (Crumpacker et al., 2000).

Most protected areas are primarily aimed at protecting biodiversity, a role that is stressed in the IUCN definition of a protected area: *An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means* (Anon, 1994). Such protection can range from providing a secure base for species that spreads far beyond the border of protected area networks, such as the giant panda that is protected through a reserve network but also lives in unprotected forests and mountains, to protecting the entire known population of endemic species with a strictly limited distribution. The increased stress on biodiversity created by climate change therefore increases the arguments for protected areas. To some extent their role here is mainly to reduce other threats by maximizing the resilience of the ecosystem and to provide large, unbroken blocks of habitat that will be relatively resistant to environmental change. But managers are also looking at other actions to address climate change at a site and network level, including active restoration to help speed up changes in vegetation patterns created by temperature difference; translocation programs for threatened species; and active management of patch dynamics. Experience with translocation at a habitat scale is not encouraging (Hodder and Bullock, 1997) although translocation of individual species may be more realistic. Using protected areas to conserve biodiversity in the face of climate change often means cooperating between protected areas and also often between countries (or other geographical/managerial jurisdictions), adding weight to arguments for transboundary protected areas.

The practical implementation of these challenges is starting to be worked out by protected area agencies, researchers and managers, often working in cooperation. In the Netherlands, a new national conservation plan looks specifically at increasing options for migration between protected areas and a process of "de-fragmentation" pursued with a target that: "by 2020 migration within and between nature areas will be secured by removal of physical barriers" (Anon, 2000). A review undertaken for the UK government identified three policy responses: the possible need to redraw boundaries of protected areas and re-designate sites as habitat for particular species shifts; managed changes particularly inshore from seawater defenses to recreate coastal habitat before this is flooded, including restoration and the use of holding reserves for species; and translocation of species with a narrow distribution, such as the Snowdon Lily *(Lloydia serotina)* (Hossel et al., 2000). In the high Arctic, scientists working in a series of UNESCO biosphere reserves including Abisko (Sweden), Zackenberg (Greenland), Taimyrsky (Russian Federation) and Niwot Ridge (USA) are measuring responses of certain plants to changing conditions and developing management responses (Arft et al., 2000). In North America, cooperation between the Mapini Biosphere Reserve in Mexico and the Big Bend Biosphere Reserve in Texas, USA, is examining options for translocation of the endangered Bolsón tortoise *(Gopherus flavomarginatus)* further north as a response to climate change (Hadley, 2002).

Water Security

In the past 100 years the world population tripled, but water use for human purposes multiplied six-fold (World Water Council, 2000). Water security is already an important and sometimes politically explosive issue and this is likely to intensify under climate change. After the 1992 Earth Summit, *Agenda 21* noted that: "Higher temperatures and decreased precipitation would lead to decreased water-supplies and increased water demands; they might cause deterioration in the quality of freshwater bodies, putting strains on the already fragile balance between supply and demand in many countries". The IPCC has repeatedly identified potential problems with water supply, particularly in arid regions.

Protected areas are increasingly being used to guarantee the quantity and to an even greater extent the quality of the water that we use, including particularly urban drinking water. As with some of the other links discussed above, this relationship is not without controversy.

There seems to be no constant relationship between presence of forests and *quantity* of water, and simplistic claims that forests increase or stabilize water supply are often incorrect. Exceptions to this appear to be cloud forests that do intercept water and may increase flow. In addition, some old forests also increase net water flow. Studies of rainfall and runoff data in Australia collected from large forested catchments in the Melbourne area that were completely or partially burnt by a large-scale wildfire in 1939, concluded that the amount of water yield from forested catchments is related to the forest age. It was found that forest disturbance can reduce the mean annual runoff by up to 50% compared to that of a mature forest, and can take as long as 150 years to fully recover (Kuczera, 1987).

In addition, and more importantly, natural forests in catchments do often appear to have a beneficial impact on water *quality*, thus reducing the very high costs of purifying drinking water. Forested catchments can therefore play an extremely important economic role in reducing costs of purifying water and in situations where clean water is not universally available they can also help improve public health.

Drinking water supplies provide a clear example of how the link between climate change, hydrology and water supply might relate to protected areas. Currently a third of the world's top hundred cities rely on protected forests for some or all of their drinking water and some, such as Melbourne, Dar Es Salaam and New York have made well-publicized links between forest protection and purity of water supply. Others, like Istanbul and Bangkok, suffer from water supply problems in part because of environmental deterioration in their watersheds (Dudley et al., forthcoming). In most cases, protected areas are important principally because of increased water purity while in some cities they are also believed to increase net quantity of water available. Many municipal authorities have pre-empted the debates amongst hydrologists and protected catchments as insurance for their water supplies, particularly in cloud forest areas.

Water supply links also exist between, for example, Mumbai (Bombay) and Sanjay Ghandi National Park in India; Bogota and Chingaza and Sumapaz National Parks in Colombia; Rio de Janeiro and Tijuca National Park in Brazil; Vienna and Donau-Auen National Park in Austria; and Abidjan and the Parc National du Banco in Côte d'Ivoire. Economic studies point to the importance of these protected areas in terms of reducing purification costs. Recent studies calculated that the presence of Mount Kenya forest alone, which is within a 70,000 ha IUCN category II protected area, saved Kenya's economy more than US$ 20 million by safeguarding the catchment for two of the country's main river systems, the Tana and the Ewaso Ngiro, from deforestation (Emerton, 2001). On a smaller scale, payment for maintaining forests to insure the future of water supplies has been introduced for hydroelectric schemes, such as in Costa Rica (Rojas and Aylward, 2002), for pure industrial water, such as payments negotiated with Pepsi Cola in Guatemala (Gretzinger, pers. comm.) and for irrigation. The World Bank is currently supporting the development or implementation of Payment for Environmental Services systems in Costa Rica, Guatemala, Venezuela, Mexico, Colombia, Nicaragua, Dominican Republic, Ecuador, El Salvador and South Africa. Many of these look specifically at the impacts of protected areas on water quality. For example a project financed by the Global Environmental Facility is under preparation, focusing on Canaima National Park, with significant co-financing from hydropower producer CVG-EDELCA (Pagiola et al., 2002). As climate models suggest that water stress is likely to increase in the future, the added benefits and security provided by forest protected areas are particularly important.

The cloud forests in La Tigra National Park in Honduras are a typical example, sustaining a well-regulated, high quality water flow throughout the year, which provides over 40% of the water supply to the 850,000 people in the capital city Tegucigalpa (Dudley et al., 2003). As with mangroves and coral reefs, there is a tension here because cloud forests are also particularly prone to climate change (Bruijnzeel, 2001; Calder, 2002). Although some of the stresses on cloud forests are outside the control of managers on the ground, research suggests that climate change stress will be exacerbated by other factors, including fire, drought and plant invasions (Foster, 2001). Additionally forest loss nearby can reduce clouds and thus adversely affect cloud forests (Lawton et al., 2001). The close link between cloud forests and water resources is therefore an additional argument for devoting resources to cloud forest protection and for those responsible for developing national or ecoregional protected area networks to include provision of water amongst the arguments for protection of tropical montane cloud forests.

Crop Genetic Stress

Changing climate will increase stress on both new and traditional crop varieties and the IPCC has repeatedly referred to the need for crop breeding to respond to these changes (McCarthy et al., 2001). Changes in agriculture have tended to increase risks by radically reducing the number of crop varieties, for example research by the Rural Advancement Fund International found that 97% of the varieties given on old United States Department of Agriculture lists are now extinct (Fowler and Mooney, 1990). Rice production provides an example of extreme cultivar uniformity, with 75% of rice varieties grown in Sri Lanka descending from one maternal parent, a uniformity mirrored in Bangladesh and Indonesia (Groombridge, 1992). Wild relatives of modern crops therefore have a particularly important role to play in kick-starting the breeding of new strains under time pressure. Unfortunately many of these have virtually disappeared from their original centers of diversity in areas of Europe, the Middle East, Africa and Asia.

Protected areas are one specific response to this loss of agricultural biodiversity and an increasing number are being designed specifically to protect sources of crop genetic material. The potato provides a good example. Modeling suggests that there will be increased potato yield variability for Europe (Wolf, 2000), increasing risk of crop failure. In response to these and other threats, potato conservation is being highlighted in the Andes, where the wild ancestors originate. At Pisac Cusco, in Peru, seven Quechua communities are planning to establish a “Potato Park”; a community-based conservation area focused on agri-biodiversity, managed through an integrated landscape model. The area is a recognised centre of crop diversity for potatoes and other important Andean crops (e.g. Quinoa, Kiwicha, Mashua). It lies at the heart of the ancient Inca Empire (and it is suspected that the Incas brought potato varieties from other parts of the continent). The aim is to protect and conserve native plant genetic resources as well as associated traditional knowledge and local cultural heritage. The initiative addresses local concerns regarding food security, poverty alleviation, gender equality, intellectual property and the right to self-determination for indigenous peoples. It aims to include ecotourism, the marketing of native crops and capacity building in sustainable agriculture. Peruvian authorities and institutions such as the International Potato Centre recognise the value of the scheme and a committee of government and non-governmental organizations is studying legal options for formal recognition. Indigenous peoples are learning of their rights to biological resources and of the potential benefits derived from their use (Phillips, 2002).

Food Security

Climate change will also disrupt agricultural systems and fisheries. While there will be both winners and losers in the resulting shifts in centers of food production, all the signs are that the poor—especially those living in marginal environments—will be the most vulnerable (Downing et al., 1996). The IPCC estimates that by the 2080s about 80 million extra people will be at risk of hunger. Yields are likely to fall particularly in the tropics, where some crops are already near their maximum temperature tolerance (McCarthy et al., 2001). Protected landscapes and seascapes provide a potential buffer in three ways: by providing breeding grounds for commercial species, by providing wild foods to the poorest members of society in time of agricultural failure and by preserving genetic resources needed for adaptive breeding.

SUSTAINING FISHERIES: There is still considerable debate about the likely impact of climate change on fishery resources, although an increasing consensus is developing that climate change will have both positive and negative impacts on the abundance and distribution of marine fish. There are concerns that where climate change impacts reduce fish stocks, this loss combined with over-fishing could lead to serious impacts for coastal subsistence communities and on countries' economic performance. Strategies to address climate change effects must therefore minimize pressures on fish stocks and provide the best conditions for their maintenance. The IPCC identifies an important role for marine reserves: "Adaptation measures that are relevant to the fishing industry may include the following: …Organization of marine biosphere reserves and protected areas for the habitat of marine mammals" (McCarthy et al., 2001).

Unlike terrestrial protected areas, where the initial incentive has usually been wildlife conservation, many marine protected areas start with an aim of maintaining fish stocks. The presence of no-take zones and strictly protected zones often deliberately coincide with spawning or nursery areas for fish. Because marine protected areas are generally newer (less than 1% of the ocean is in a protected area compared with over 10% of the land), they have often included stakeholder approaches from the beginning, allowing their planning and demarcation to be subject to far more negotiation and buy-in than with early land-based protected areas.

Until recently, links between marine protected areas and increased fish stocks were based largely on un-quantified observations by villagers and protected area managers. A series of research projects has now provided more concrete evidence that marine protected areas increase the numbers, biomass and variability of fish and that they have a significant export to surrounding waters, so that fishing communities operating nearby see an increase in catch (Gell and Roberts, 2003). Significantly, they show that MPAs provide insurance against environmental variability and year-to-year fluctuations: the conditions that are predicted to increase under climate change. A review of 80 marine protected areas found that on average reserves doubled abundance, tripled biomass and increased both size and diversity of fish by a third (Halpern, 2003) and the same data showed that increases usually became obvious within five years of protection (Halpern and Warner, 2002). Research projects in Kenya around the Mombassa Marine Park (McClanahan and Mangi, 2000) and in St Lucia in the Caribbean (Roberts et al., 2001) are both typical in finding increased catches around MPAs as compared to other nearby fishing areas, and local fishing deliberately targeting areas near the reserve ("fishing the line"). This evidence is building public support for marine protected areas as a long-term insurance policy. The 1500 km^2 marine component of the new Quirambas National Park in Mozambique has been developed and agreed with local communities in part to protect fish breeding grounds (WWF Endangered Seas Campaign, pers. comm.).

Many current reserves are too small to have a significant impact on fisheries. A recent review (Roberts and Hawkins, 2000) and theoretical modeling exercise (Pezzey et al., 2000) both suggested that larger reserves were often required, with ideally between 20-40% of fishing grounds being set aside, with the amount of protected area increasing with fishing intensity. The presence of reserved areas to help buffer against fluctuations caused by ENSO events and other fluctuations is likely to become increasingly important. However, enforcement effectiveness has been highlighted as a major problem for marine protected areas (Jameson et al., 2002) and their role in maintaining fish stocks depends on the rigour with which governments and local communities are prepared to enforce their protection.

NON-TIMBER FOREST PRODUCTS AND GAME: Throughout history, poor people have collected wild foods in times of shortage, including game and non-timber forest products. This pattern continues, both in the developing world where, for instance, wild game forms 70-90% of protein intake in parts of Africa (Sayer and Ruiz-Perez, 1994) and in Europe and North America, where recent immigrants are reviving non-timber forest product (NTFP) harvests (Hansis, 1996). Natural forests are acknowledged as serving as "safety nets" for the rural poor (Wunder, 2001), and this role is likely to become more important under climate change because sources of agricultural food will become increasingly stressed and liable to seasonal failure under fluctuating climate conditions.

The extent to which protected areas can be included in this safety net is the subject of practical research projects around the world. In places where large-scale land conversion has occurred, they may be the only source of some wild foods. The collection of NTFPs and game from protected areas has traditionally been seen as a management "problem", and indeed unregulated collection can cause serious biodiversity losses (Barnett, 2000), even for subsistence purposes (Noss, 1998). However, protected area managers are increasingly working with local communities, not to ban collection and hunting but to manage it on a sustainable basis. This has immediate social benefits and if local people are allowed controlled access to resources they have more incentive to work with rangers in controlling organized poaching.

Programs to implement sustainable use of wild species have been introduced in many protected areas, so far mainly for reasons other than climate change: the following two examples are from Africa. Bwindi Impenetrable Forest Reserve in Uganda (IUCN category II, 32,000 ha) is home for half the world's remaining mountain gorillas along with important populations of chimpanzees and elephants. It is surrounded by agricultural land, up to the park borders in some places: although soil is fertile, agriculture takes place on steep slopes and in sometimes harsh climatic conditions. To address local resentment at the introduction of protection, agreements have been reached with 21 neighboring parishes to collect NTFPs, including medicinal plants and handicraft species, and to practice beekeeping. Twenty percent of the park has been reserved for this purpose, with collection areas changing over time to maintain populations. Local people collaborate with rangers in collecting information about changes in population of desired species (Makombo, 2001 and information collected on site), thus building experience on how the protected area can be harvested sustainably.

Lobéké National Park in Southeast Cameroon has followed a similar pattern, although here negotiation with communities started as soon as the park was agreed, being run as a WWF project since 1995. Lobéké is in a less heavily populated area than Bwindi and is surrounded by forest, although the latter has generally been logged. The key need of communities is for game. Through a detailed stakeholder consultation, based around the principle of exchange—rights for responsibilities—five community-managed hunting zones have been agreed covering 200,000 ha along with other forms of collection (Hakizumwami, 2000 and information collected on site). It is hoped to avoid the problems of over-exploitation and consequent loss of both biodiversity and meat sources that have plagued other protected areas in Africa.

Conclusions: What Does This Mean for Protected Area Agencies?

This review has shown that, at our present levels of understanding, protected areas have much to offer in terms of helping to maintain food security in times of climate change, benefits in terms of both water security and various forms of protection against disaster on land (although the particular implications under climate change remain obscure in some cases), a key role in controlling coastal erosion and a general role in relieving ecosystem stresses such as fire.

In summary, protected area managers can in many instances contribute to wider efforts at mitigating climate change impacts and incidentally increase support and perhaps resources for management. Key points that have emerged from the following review are:

MAINTAIN AND INCREASE LARGE RESERVED AREAS: Large, unfragmented reserves are likely to be most useful in both resisting climate change and providing resilience within a landscape – increasing core reserve areas, linking reserves and developing effective buffers are therefore crucial first steps.

PLAN PROTECTED AREAS WITH DISASTER MITIGATION IN MIND: protected areas can play an important local role in protecting communities from climate-related floods and landslips and can play a nationally important role in terms of avalanche and coastal protection. As reefs, mangroves and upland forests are also at risk from climate change, choice of where best to put management resources should also be influenced by protective functions.

RECOGNIZE THE ROLE OF PROTECTED AREAS IN MAINTAINING TERRESTRIAL FOOD AND WATER SUPPLIES: the examples given show that small changes in management attitudes and practices can in many cases allow the natural vegetation within protected areas to help supply emergency food and forage and plentiful water, all likely to be in shorter supply in the future.

SITE MARINE PROTECTED AREAS TO MAINTAIN FISHERIES: as fish stocks suffer from multiple problems of over-exploitation, pollution and climate change, ways of maintaining breeding stocks become more important. The beneficial role of MPAs is now proven and the need to maintain fisheries should be a major factor in increasing reserve coverage from the current 1% of the ocean that is protected.

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