Overview
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A vast array of scientific literature now makes it abundantly clear that the climate is changing and ecosystems are being affected by these changes. Much as awareness has been raised about invasive species, environmental contaminants, altered hydrology, and habitat fragmentation, conservation practitioners must now address climate change. This manual aims to assist natural resource and protected area managers as they begin to consider how to respond to this growing threat.

The need to respond couldn't be clearer; effects of climate change are now visible around the world. This year two large-scale studies demonstrated a global ecological fingerprint of climate change. To resolve differences between economists and biologists over the strength of climate change effects in natural systems, Parmesan and Yohe (2003) analyzed data on more than 1700 species to show with a "very high confidence" level (IPCC definition) that climate change has already altered range boundaries and phenology. A separate study using data from 143 studies found that 80% of species studied showed trait changes consistent with climate change-driven predictions (Root et al., 2003).

In each of the biomes discussed in this manual there are examples of specific climate-related changes. The thickness and extent of Artic sea ice has reduced dramatically; in 2002 ice coverage was the smallest it has been since records began (Serreze et al., 2003). Coral bleaching has drastically changed some reef communities and while bleaching was once a rare and localized occurrence it is now a global phenomenon (Glynn, 1993; Hoegh-Guldberg, 1999). Montane glaciers are shrinking around the world, and rates of retreat are generally accelerating (Haeberli et al., 1999). Increases in surface water temperatures in Lake Tanganyika, a deep tropical lake in East Africa, have reduced annual mixing, causing nutrient depletion in the upper layers of the lake and have reduced primary productivity by 70% since 1975 (Verburg et al., 2003). In the highland rainforests of Monteverde, Costa Rica, the lifting of the cloud base associated with increased ocean temperatures has been linked to the disappearance of 20 species of frogs. (Pounds et al., 1999). On a rocky shoreline in central California, where annual mean ocean temperature has increased 1^{o}C over the past 60 years, researchers have documented an increase in southern animal species and a decrease in northern animal species (Sagarin et al., 1999).

Current trajectory & the limits of adaptation
Over the past century the average global temperature has risen 0.7 ºC as atmospheric CO_2 concentrations have risen from ~280 ppm to 370 ppm. Emissions scenarios from the Intergovernmental Panel on Climate Change (2001) suggest that if humans do not act to reduce emissions we will see CO_2 levels of 550 ppm within the next 40 to 100 years, roughly a doubling of pre-industrial concentrations. This range of scenarios implies an additional increase in temperature of 1 to 5.8 ºC. Recent papers suggest that the upper end of this range is more likely and that even higher high temperatures are possible, especially if climate sensitivity has been underestimated (Caldeira et al., 2003). This higher range of temperatures will also mean greater sea level rise and greater potential changes in precipitation and oceanic currents.

Clearly most systems will be dramatically challenged and subsequently altered by changes of this magnitude. It is unlikely that any local strategies could provide adequate protection for biodiversity under these conditions. Conserving biodiversity will therefore require a two pronged approach. First, greenhouse gas emissions must be dramatically reduced in order to slow the rate and extent of global climate change. Under current scenarios, all outcomes result in dramatic changes beyond the reach of adaptive measures. WWF proposes that we aim to reduce greenhouse gas emissions to limit change to less than a 2ºC average temperature increase above pre-industrial levels. Second, assuming that we can limit the rate and extent of change, we will still need to respond to the change that is already inherent in the system and buy some time for ecosystems as emissions are reduced. Because the effects of greenhouse gases in the atmosphere have a substantial lag time we are locked into additional change from the concentrations of greenhouse gases already in the atmosphere today. This does not mean that reducing emissions is futile; rather it means that we must reduce emissions quickly and deeply and take local action to protect biodiversity by increasing the resistance and resilience of natural systems so they can better survive the changes to come.

°C Temperature Change	Effect on Biodiversity
2	Some species lost Possible management options exist
4	Many species lost Few management options (those that exist will be extremely expensive)
6	Dire

Figure 1. The effects of climate change on biodiversity for three thermal thresholds. (Adapted from Parmesan, pers. comm., based on a preliminary survey of existing literature).

What is resilience building in response to climate change?
We think of this manual as a first step in developing successful adaptation strategies for natural systems conservation. The chapters outline the significant features of each biome, what threats are already affecting these biomes, likely affects of climate change to each biome, possible strategies for increasing resilience within the particular biome and finally offer suggestions and examples of how these strategies might be implemented.

Increasing the resilience of a natural system is a standard goal of conservation; intact ecosystems have more resources for withstanding stresses. Natural systems are already affected by an array of stresses, from fragmentation to pollution to invasive species. Climate change will add another layer of stress to this complex matrix of interactions. Increasing ecosystem resilience to climate change will require even greater vigilance and longer term planning. Suggestions in these chapters fall into three broad categories.

1. **Protect adequate and appropriate space**
Ecosystems with high biodiversity and those that maintain crucial structural components are thought to recover more easily from climatic disturbances. Traditional conservation methods such as creating protected areas, whether in terrestrial or marine areas, will thus have another justification in the next several decades. It will become increasingly important, however, to take into account projected impacts of climate change when designing new protected area systems, and to expand spatial scales through buffer zones and corridors to aid species migration. In particular, planners should look for climate refugia, areas that experience less change than others.

Planning reserves will now require an eye for potentially dramatic future changes in protected areas; thinking about not only current but future configurations of habitats, communities, and ecosystems. Managers will need to be even more strategic, creative and flexible in designing protection strategies to address traditional land uses, existing threats, and also climate change stresses. Protecting not just space but functional groups, keystone species, climatic refugia, and multiple microhabitats within a biome to provide adequate representation is essential.

2. Limit all non-climate stresses

Climate change is not occurring in a vacuum. There are myriad stresses affecting natural systems, including habitat fragmentation, overharvest, invasive species, and pollution. A limited body of research on interactions between climate and non-climate stresses suggests synergistic responses (McLusky et al., 1986). For example, when rainbow trout (*Salmo gairdneri*) are exposed to the pesticide permethrin over a range of temperatures, the toxicity increases as temperature increases (Kumaraguru and Beamish, 1981). To support ecosystem resilience you must reduce the number of simultaneous insults faced by that ecosystem. Fortunately many stressors are more locally controllable than climate change. In a marine system this may mean establishing "no-take zones" to reduce fishing pressure and associated habitat destruction. In a freshwater system this may require limiting the concentration of toxic substances in effluent from an upstream industry. It may mean protecting alpine watersheds by limiting extraction of water by downslope agriculture and cities, or limiting harmful grazing practices in grasslands. Forests could require limiting fragmentation from road construction and logging. None of these tasks are easy, but they are approachable on a local level.

3. Use active adaptive management and strategy testing

Given uncertainty about the exact nature of ecosystem impacts of and responses to climate change, effective management of protected areas will require a responsive and flexible approach. The success of various conservation approaches should be continually reassessed, and approaches adjusted as new information becomes available. In instances where impacts are relatively clear, active intervention to increase adaptive capacity coupled with monitoring is necessary. Such intervention may include assisted migration or reintroduction of species, , non-chemical control of pest or disease outbreaks, prescribed burning or other fire management strategies to lessen the impact of increasingly severe and frequent wildfires, controlling invasive species and decreasing nutrient-enhanced run-off into marine and freshwater ecosystems. Where extinction in the wild is inevitable, *ex situ* conservation of species via the collection of germplasm, seedbanks, gardens, aquaria or zoos can be used as an option of last resort.

Regardless of management strategy, on-going monitoring is essential to assure that actions are truly of the "do no harm" variety. Monitoring with adaptive management sets up an *in situ* experiment, providing data for modification of management strategies and allowing for exchange of results between protected areas for better strategy development world-wide.

Methodologies for evaluating climate change impacts

Chapters in this report evaluate existing and predicted effects of climate change on different biomes. Impacts that have already been seen are reported from case studies in the scientific literature. Predicted impacts are approached in a number of ways. At a large scale, it is possible to predict major shifts in biome types by combining biogeography models such as the Holdridge Life Zone Classification Model with general circulation models (GCMs) that project changes under a doubled CO_2 scenario. Biogeochemistry models simulate the gain, loss and internal cycling of carbon, nutrients, and hydrologic impacts of changes in temperature, precipitation, soil moisture, and other climatic factors that give clues to ecosystem productivity. Dynamic global vegetation models integrate biogeochemical processes with dynamic changes in vegetation composition and distribution. Comparing present trends in species and communities with paleological data also provides indications for how they will weather future climate change. (Hansen et al., 2001)

The role of the U.N. in developing National Adaptation Plans
Under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, countries are required to develop national adaptation plans. These plans must include strategies for biomes, but very little work has been done thus far to ensure that these crucial natural resources are included in national adaptation strategies. It is WWF's hope that this manual will provide a tool to assist in completion of the biodiversity portion of natural adaptation plans so that countries have strategies in place to buy time for biodiversity and natural resources. Numerous conversations are currently underway around the world noting the need for further support, both financial and intellectual, for adaptation strategies. While adaptation plans cannot in any way replace mitigation, they are vitally important to ensure that all countries receive the support necessary to protect their natural resources, especially those countries where such support is currently unavailable. Thus far support has been inadequate, especially for developing countries.

The importance of integrating climate change threats into conservation plans
Conservation planning is the key to protection of biodiversity and ecosystem function. The majority of planning to date has focused on issues relating to space, designing reserves to protect moderately "pristine" tracts of land or water. While we have protected only a fraction as much area as needed to meet recommended spatial goals, we must also start to address threats arising outside reserves and protected areas. Environmental threats like climate change require that we extend conservation planning beyond the boundaries of protected areas, and into a future in which ecosystems and biomes may be quite different than they are today.

We must also realize that while it is incumbent on us to take action now to design, test and adopt conservation strategies that respond to climate change, these efforts are not the long-term solution. Even the best-designed approaches to increasing resistance and resilience to climate change will work only for changes of a few degrees at most. In essence, we are only buying ecosystems time, but time they desperately need while efforts are made to stabilize atmospheric concentrations of greenhouse gases and limit the rate and extent of climate change.

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