# What Should Protected Areas Managers Do in the Face of Climate Change?

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## The face and pace of change, past and future

**Climate change across geological time.** Climate has always been changing, is changing, and will continue to change. Throughout geological deep time the Earth witnessed long warm phases interspersed with ice ages, with perhaps even a "snowball Earth" occurring as many as four times between 750 million and 580 million years ago (Hoffman and Schrag 2000). Surface temperatures across all latitudes rose by 6°C to 8°C at the start of the Eocene epoch 55 million years ago, corresponding to massive increases in atmospheric carbon triggered by large-scale igneous activity and hydrate melting under what is now the Norwegian Sea (Svensen et al. 2004). Over the past 4 million years, the Earth has gone from global surface temperatures about 3°C warmer than today, with smaller ice sheets and higher sea levels, to the current cooler conditions (Ravelo et al. 2004). The 1.8 million years of the Pleistocene and Holocene epochs were characterized by roller-coaster swings of many degrees Celsius, corresponding to glacial intervals and abrupt warming at the onset of interglacials (Folland et al. 2001; Figure 1). While driven by 100,000-year cycles in the shape of Earth's elliptical orbit and 40,000-year cycles in its rotational tilt, there has also been a close association between climate and greenhouse gases, such as carbon dioxide and methane, over as much as the last 740,000 years (EPICA 2004). Within historical times, our planet experienced several temperature shifts, such as the Medieval Warm Period and the late 19th century Little Ice Age (Figure 2). During the last century, average annual precipitation changed up to 50% in some regions (Figure 3).

**Recent climate change.** While rapid in terms of geological time scales, these changes were, well, geological in pace. Over the past 100 years, however, global average temperature has risen approximately 0.6°C, and the rate of warming has greatly accelerated since the 1970s (Figure 2). This change is ascribed mainly to rapid and large releases of greenhouse gases from the burning of fossil fuels for power generation and transportation (IPCC 2001a). It is even possible that were it not for increased releases of $CO_2$ and $CH_4$ due to the burning of forests to clear land for agriculture, starting around 8,000 years ago, and the invention of rice paddy cultivation about 6,000 years ago, the Earth would have already entered the next glacial interval (Ruddiman 2003).

**Impacts of recent climate change.** There is ample evidence of the physical and ecological impacts of recent climate change. Walther et al. (2002) summarize many of these observed changes, such as increased

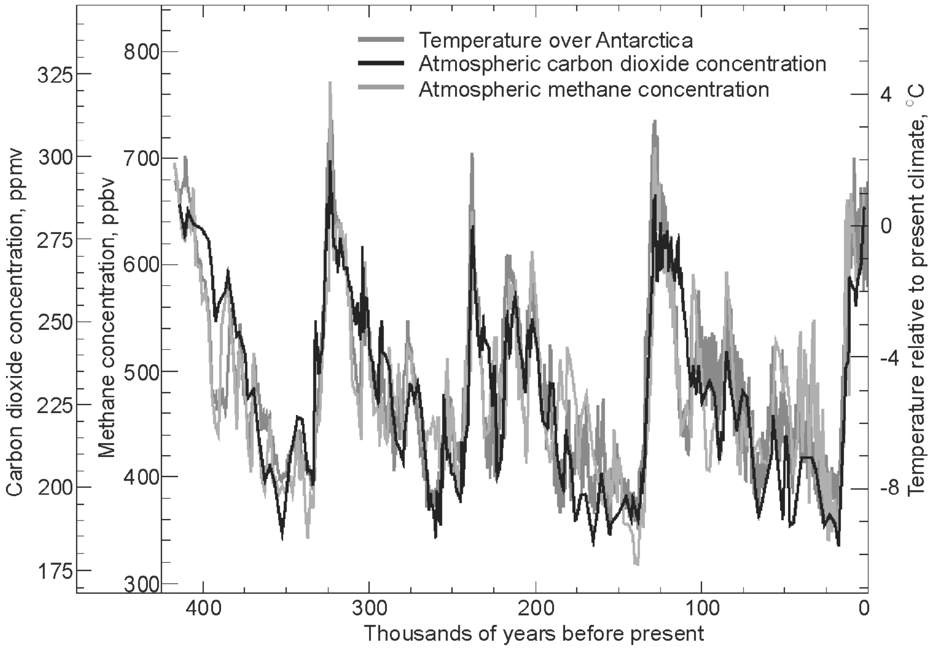


Figure 1. 400,000 years of temperature history. Source: Folland et al. 2001, Figure 2.22, page 137. *Reproduced courtesy of the Intergovernmental Panel on Climate Change*

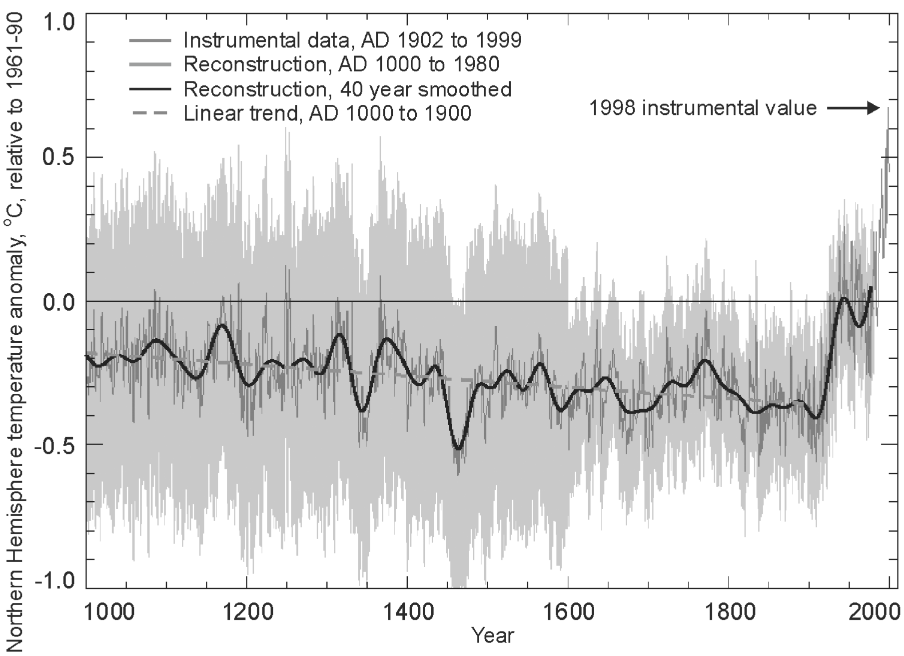


Figure 2. 1,000 years of temperature history. Source: Folland et al. 2001, Figure 2.20, page 134. *Reproduced courtesy of the Intergovernmental Panel on Climate Change*

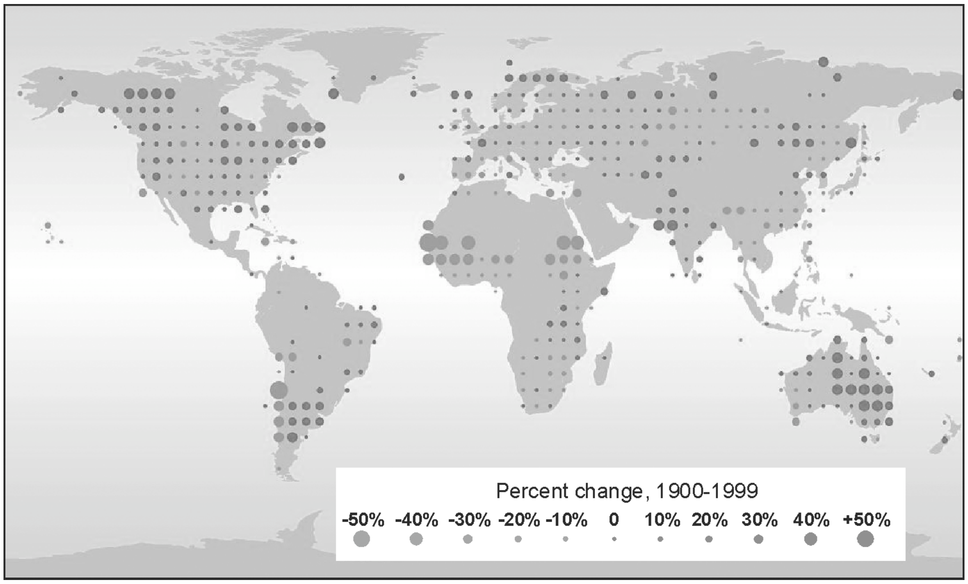


Figure 3. 100 years of precipitation history. Source: Folland et al. 2001, Figure 2.25(ii), page 144, and presentation graphic 2-6a. *Reproduced courtesy of the Intergovernmental Panel on Climate Change*

temperatures in North America and Europe leading to northward range shifts in 39 butterfly species of up to 200 km over 27 years. In a meta-analysis of over 1,700 species Parmesan and Yohe (2003) find average range shifts of 6.1 km/decade poleward and meters per decade upward, and spring event advances of 2.3 days/decade. In another meta-analysis of 143 studies of 1,473 species, Root et al. (2003, 57) say that "the balance of evidence from these studies strongly suggests that a significant impact of global warming is already discernible in animal and plant populations." McCarty (2001) cites numerous specific studies, and observes that in recent decades global change is apparent at all levels of ecological organization, and that this can be linked to climate change, among other stresses. The Geological Survey of Canada has compiled pollen, macrofossil, and buried mammal data to produce 1,000-year interval maps of the biomes of glaciated North America since 18,000 years before the present (Art Dyke, personal communication). The boreal forest, for example, first appeared in southern Iowa and Ohio and has since sought refuge in Canada. Its southern limit is now 1,000 km north of its former northern limit. Overland et al. (2004) conducted an integrated analysis of 86 time-series data types for the Arctic, including atmosphere, ocean, terrestrial, sea ice, fisheries, and other biological data. Their first three principal components show that the Arctic acts as a coherent system, tying the atmosphere to fisheries and other biota.

**Future climate.** Geological proxy records and historical and contemporary direct measures all show a strong correlation between global climate and the atmosphere's concentration of greenhouse gases. Our understanding of atmospheric physics also bears witness to this link. This connection is recognized by the United Nations Framework Convention on Climate Change and the Kyoto Protocol. The Intergovernmental Panel on Climate Change (IPCC 2001a) proposes several scenarios for anthropogenic emissions of carbon dioxide, methane, and other greenhouse gases over the next century. These have been factored into various general circulation models, yielding the alarming result that the annual average global temperature may rise between about 2°C and 6°C by 2100 (Figure 4). The range of projections is mostly related to the range of emission scenarios; that is to say, they are dependent upon the policies that humankind chooses to follow. Global averages, of course, hide regional trends, several of which show up in most models. Warming will be greater in continental interiors. Areas of high precipitation will get wetter. Arid zones will get dryer. Warming will increase towards the poles and will be greater in winter. For example, Figure 5 shows the scatter of annual temperature and precipitation projections for two Canadian national parks, Waterton Lakes on the Alberta–Montana border at 49°N and Quttinirpaaq at the north end of Ellesmere Island, 82°N.

Some caveats apply. While all models agree on a warmer planet, some show regional cooling, e.g., over the Labrador Sea. As well, the monthly pattern of warming varies considerably. In the example of Wapusk National Park, at 58°N on the shores of Hudson Bay in Manitoba, six model–emission scenario combinations give the peak warming month as either January or February, a secondary peak in

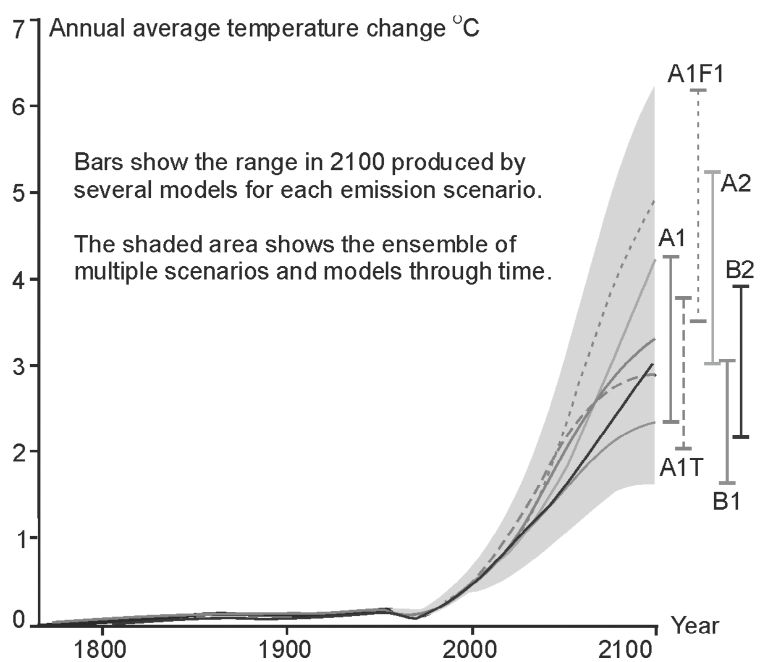


Figure 4. Global temperature projections for different emission scenarios. Source: Cubasch et al. 2001, Figure 9.13b, p. 554, and presentation graphic TS22. *Reproduced courtesy of the Intergovernmental Panel on Climate Change*

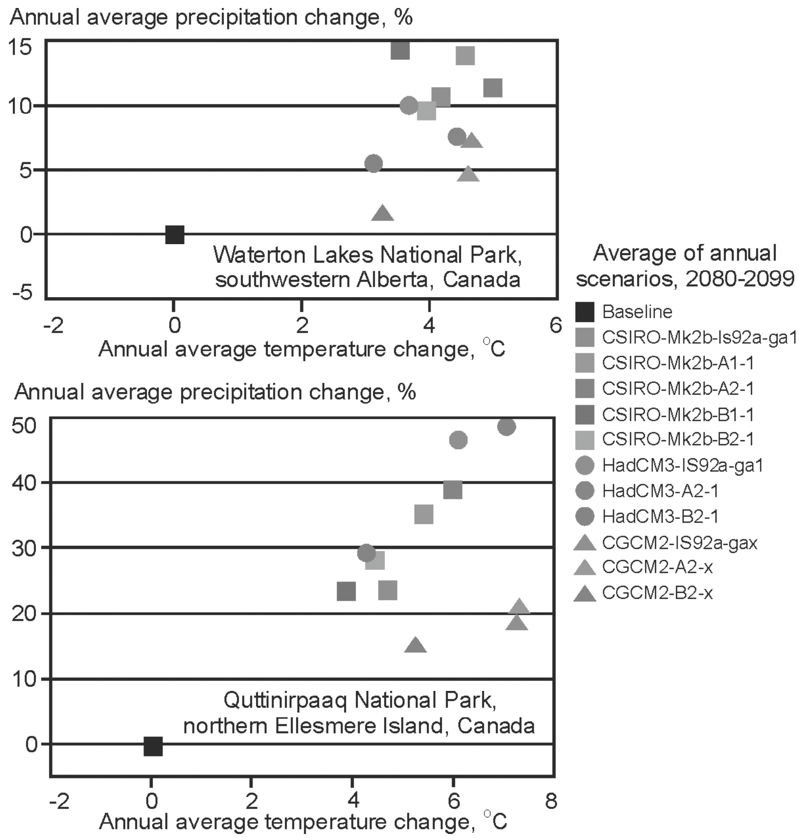


Figure 5. Temperature and precipitation ensembles for two Canadian national parks. Source: Scott 2003.

April or June, and a range of up 2°C to 7°C in the month-to-month degree of warming (Figure 6).

**Impacts.** Such climate changes will drive physical and biological changes on the Earth's surface at least as great as has been seen throughout the Holocene epoch, during which large parts of North America witnessed wholesale biome changes. A recent study for Parks Canada (Scott et al. 2002; Scott 2003) examined several vegetation change models matched to climate models. In five of six vegetation scenarios, the biome would change in more than half of Canadian national parks in a $2xCO_2$ world (i.e., one with doubled carbon dioxide concentrations). Of course, biomes won't actually move intact and in concert with climate. Most plants, many habitats, and all ecosystems cannot migrate in step with the regional shifts of climate patterns. Instead, we should expect many novel biomes and an increasing dominance of pioneer species. Ecosystems will develop into early successional stages and be net emitters of carbon dioxide (Walker and Steffen 1997). The distribution of ecosystem changes, as expressed through biome, biomass, net primary productivity, and leaf area index, will result primarily from changes in the hydrological cycle (Higgins and Vellinga 2004). There will be enormous hydrological

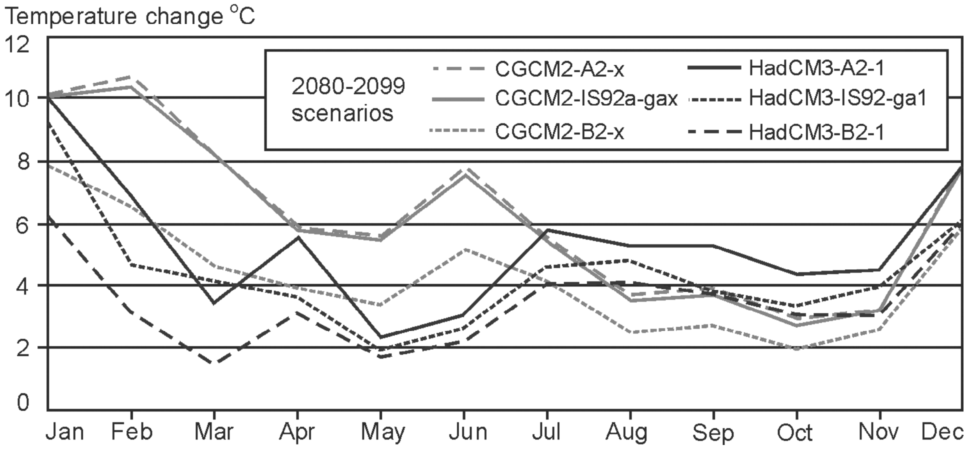


Figure 6. Monthly temperature scenarios for Wapusk National Park. Source: Scott 2003.

changes in areas currently dominated by snowfall and minimal evaporation or runoff during winter months. More precipitation will fall as rain rather than snow. Runoff will shift from spring peaks to a more even year-round flow, so that less water will be available during summer irrigation and navigation seasons. Warmer summers will evaporate more water. Even if total precipitation were to increase, the resulting combination will probably mean lower lake levels, dryer wetlands, and greater shortages of available water (Schindler 2001). These changes will be particularly acute in mountain regions (Beniston 2003).

Other potential impacts include the following:

- Increases in the frequency and magnitude of extreme events such as storms and floods.
- Rising global sea levels and the accelerated retreat of low-lying coastlines.
- Declining Arctic sea ice extent and duration, leading to changes in marine mammal distributions and navigation and greatly increased coastal erosion.
- Accelerated melting of permafrost, reducing trafficability and soil stability.
- The loss of glaciers in middle and equatorial latitudes. The expected disappearance of glaciers from Glacier National Park, Montana, has become a well-known poster child for climate change impacts (Hall and Fagre 2003).

As well as these immediate physical changes, new environmental conditions will foster profound changes in the biotic composition of ecosystems, not just due to changes of temperature and water regimes but also, for example, due to the increased ability for invasive pests, pathogens, and weeds to migrate into new regions.

In sum, the weight of scientific evidence shows that climate change anticipated in the 21st century will result in new vegetation successions, water regimes, wildlife habitat and survival conditions, permafrost and surface ice conditions, coastal erosion and sea-level change, and human responses, including tourism opportunities (IPCC 2001a; Hansen et al. 2003). Many countries recognize these threats through their ratification of the Kyoto Protocol on climate change and through their national action plans and government programs that address the impacts of climate change and how their peoples may play a part in mitigating and adapting to it.

### Why and when to adapt?

"Human and natural systems will to some degree adapt autonomously to climate change. Planned adaptation can supplement autonomous adaptation, though options and incentives are greater for adaptation of human systems than for adaptation to protect natural systems" (IPCC 2001b, 8). Protected areas will be affected by climate change at least as much as other lands and waters in their natural regions. Indeed, the impacts may be greater. Fewer mitigation and adaptation options exist than for lands and waters that are actively manipulated. Protected area custodians must therefore seek ways to adapt their management practices to help maintain biodiversity and natural processes, to assist nature through its inevitable transitions, and to participate fully in programs aimed at reducing greenhouse gas emissions.

Adaptation means adjustments in practices, processes, and structures. It can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions (Smit et al. 2001). Protected area agencies should plan their adaptation in anticipation of greater rates of change than have previously occurred. When something wicked this way comes, it is better to be prepared than to be surprised. Early adaptation is encouraged for a number of reasons:

- Climate change is already occurring and further changes cannot be prevented, so there is no justification for a wait-and-see policy.
- No regrets. Benefits can be obtained by removing or halting maladaptive policies and practices that may increase vulnerability.
- Risk management. Benefits can be obtained by adapting in anticipation, rather than reactively, particularly if other stressors are mitigated.
- Investment. Visitor activities are tied to the timing and duration of annual climatic cycles and phases. Long-term investment in infrastructure and marketing, by concessionaires and park management agencies alike, must take future climate into account.
- House in order. Effective government is abetted by leadership by example, particularly in free-market societies. In the present context, this means early achievement of greenhouse gas emission reductions from park operations and the adoption of adaptation policies.

### How to adapt ... maybe

**Social and policy adaptation.** So what should protected area managers do in the face of climate change? A great deal has been written about vulnerability and adaptation. The Intergovernmental Panel on Climate Change provides a comprehensive summary organized around global-scale ecosystems and societal and governmental responses (IPCC 2001b). Many journal papers address this subject, but, again, from an economic, infrastructure, and social policy standpoint. One example is by Kelly and Adger (2000), who focus on reduction of vulnerability to climate change, economic equity, and well-being achieved through poverty reduction and spreading risk through income diversification. More recently, Easterling et al. (2004) focus on the United States and responses in areas such as disaster management, regional and economic-sector disparities, and institutional reform. While very little can be gleaned for protected areas from such reports, two lessons stand out. One is that possibly the best tack for park managers is to reduce vulnerability to the effects of climate change by maintaining as many options as possible for resilience—the ability to recover quickly after a disturbance. The other lesson is the need to customize adaptation strategies to specific interest areas. For readers of this journal, this mean parks, reserves, and other managed natural landscapes.

**Protected areas adaptation.** Some papers do address conservation and biodiversity. Considering the conservation of biodiversity in a changing climate, Hannah et al. (2002) call for conservation strategies responsive to the changes that are inevitable. In their view, these conservation strategies require the following.

- Regional modeling of biodiversity response to climate change.
- Incorporation of climate change as a factor in the selection of protected areas.
- Regional management of biodiversity, including core protected areas and landscape connectivity.
- Local to international coordination of protected area management.

This theme was also taken up by Noss (2001). Although targeting forest managers, many of his recommendations can be adapted to all types of protected ecosystems. Here are examples.

- Represent vegetation types and diverse gene pools across environmental gradients in reserves.
- Protect climatic refugia at all scales.
- Avoid fragmentation and provide connectivity.
- Provide buffer zones for the adjustment of reserve boundaries.
- Maintain natural processes and successional regimes.
- Conduct research to identify sensitive biomes.
- Conduct long-term monitoring to seek causality between climate and biodiversity responses at several levels of organization (Noss 2001, 586).

Protection strategies for parks were specifically addressed in 1990 by Wein et al. Their management recommendations include the following.

- International exchanges of ideas between researchers and managers.
- Strengthen the research capacity of parks personnel.
- Involve local communities.
- Use parks as benchmarks for long-term monitoring.
- Determine the necessity to transplant species, or to control rapidly increasing species.
- Locate parks with climate change in mind, develop contingency plans to expand conservation areas, and protect or establish connecting corridors.

The World Wildlife Fund has published an on-line guide for natural area managers to build resistance and resilience to climate change (Hansen et al. 2003). It urges natural resource managers to build climate change adaptation strategies into their preservation philosophies and plans.

Most of its chapters are organized around environments such as forests, the Arctic, and tropical marine ecosystems. Its eighth chapter addresses protected areas. Some pertinent suggestions are contained in that and the overview chapter.

- Use active adaptive management and strategy testing.
- Integrate climate change threats into conservation plans.
- Plan protected areas with disaster mitigation in mind.

In sum, the limited literature on protected areas and climate change provides strong arguments as to why parks and reserves should be given enhanced protection, why there should be more of them, how they might be selected and what ecological services they may provide to society. However, it provides little guidance to the managers of already established protected areas.

### What to do?

Parks Canada has completed a science assessment of climate change impacts and scenarios specific to each national park, and the time is now right to consider a climate change adaptation strategy. Parks Canada has received many recommendations for actions, in print, at workshops, at conferences, and informally. This document draws from this dialogue, and the operations and policy context of Parks Canada, to lay out a slate of actions that could reasonably be undertaken in relation to climate change. Clearly, not all will apply in all circumstances, but they may be of value elsewhere. At the time of writing these ideas do not constitute Parks Canada policy. They are, nevertheless, assembled along the lines of strategy documents such as Parks Canada's Environmental Management System framework (unpublished) and the Climate Change Action Plan of the New England Governors and Eastern Canadian Premiers (NEG/ECP 2001).

**Core principles.** The development of a policy or strategy is best founded on a set of core principles or values. I offer the following.

- *House in order and public communications.* A protected area agency cannot mitigate global climate change by itself, but it can contribute to mitigations by putting its own house in order with respect to Kyoto targets, and can use its outreach and presentation activities to demonstrate leadership by example. People who visit parks and reserves are generally ready to soak up information and listen to sound arguments. The indirect role of protected areas, through interpretation, education, and outreach can be far greater than its direct contribution to emission reduction, but credibility depends on such reductions.
- *Risk management.* Climate change will bring enormous changes to the environments and processes bearing upon natural organisms and ecosystems. To various degrees they have their own degree of resilience and in many cases may be able to accommodate climate change by migration or in situ adaptation. However, there are many other stresses impinging on the ecological integrity of natural systems, so I recommend a risk management approach whereby tractable stresses are reduced or eliminated through the collaborative efforts of park agencies and their interest groups and neighbors.
- *Focus on mandate, complement with*

*partnerships.* Parks and historic sites increasingly emphasize ecological and commemorative integrity as their prime mandates, superseding considerations of tourism development, park infrastructure, and regional economic development. The latter aspects are important to the success of heritage areas, but should not be put ahead of restoring and protecting natural and cultural heritage. As well, priority should be accorded to actions within the direct responsibility of the agency and its staff. A park agency should leave to others the leadership on activities that are the responsibility of other agencies, levels of government, academia, and industry. However, to the extent that internal resources allow, and to the extent that its prime mandate is favored, a park agency should cooperate in such activities. Education, emission reduction, and national climate change science programs are good examples.

- Porous landscapes. Parks should be part of networks of ecological areas within which biodiversity can survive, move, and be appreciated. Park agencies should promote the importance of regional ecosystems characterized by connectivity and porosity for wildlife movement. This means more than defining wildlife corridors, but removing physical and non-physical impediments to movement across all lands. Examples include policies to develop and maintain hedgerows and wood lots in the agricultural domain, to eliminate the cosmetic use of pesticides in urban areas, to foster dark sky preserves, and to installing wildlife crossing alert lights on major highways, as in a Newfoundland pilot project.

**Goals.** Action plans need time-bound and measurable targets against which to assess progress, and to redefine schedules and activities as appropriate. I propose three time frames.

- *Short-term.* The appropriate level of climate change information is available to all aspects of ecosystem and asset management.
- *Mid-term.* Climate change is factored into all aspects of ecosystem and asset management, and duly reflected in park management plans.
- *Long-term.* Natural areas are nested within regional landscapes that are porous for the movement of native species, and which are free of significant threats to ecological integrity.

"Short-term" means fewer than five years, covering annual work and budget planning cycles. "Mid-term" means spanning one or two management planning cycles, i.e., five to ten years. "Long-term" means beyond a decade and encompassing the time frames of most climate change scenarios.

**Alarming actions.** An extensive suite of specific actions can be conceived to help reach these goals in accordance with the proposed principles. To provide some structure, and to help see linkages between complementary activities, they can be grouped under five categories that form the acronym *ALARM.*

- *A*wareness, including staff, stakeholder and general public awareness.
- *L*eading by example, or "house in order" actions such as reduction of greenhouse gas emissions.
- *A*ctive management, such as minimizing other stresses to facilitate

autonomous adaptation.

- *R*esearch, such as assessment of values most at risk under a radically changed climate.
- *M*onitoring, such as reporting on indicators of the impacts of climate change.

### Awareness

**Staff awareness.** Full engagement in any action depends on the knowledge and will of an agency's own staff. It is important that all staff have a level of understanding of climate change impacts and adaptation appropriate to their mission. Actions include disseminating information in summary documents, newsletters, and technical reports; giving seminar and workshop presentations; and including climate change overviews in basic training components.

**Stakeholder awareness.** Even in large North American parks, environmental protection depends heavily on the presence of a more extensive ecosystem, or buffer zone. Therefore the effectiveness of adaptation depends in like measure on the management of surrounding natural areas. A park should urge its regional ecosystem partners to respond to the need for climate change adaptations in their resource management plans. In particular this requires that they understand how climate change will influence the evolution and migration of biomes and habitats. Ideas can include promoting ecological connectivity and porosity between and around protected areas, cooperating to mitigate or eliminate all local and regional threats to ecological integrity, and communicating climate change impacts and adaptation strategies, particularly in relation to potential boundary changes.

**General public awareness.** Regional adaptations and national and international mitigation actions and policies ultimately depend on public support, expressed through politicians. Fortunately, most park agencies are well regarded by the public. They can use this esteem to promote and lobby for climate change mitigation and adaptation policies and actions, both by institutions and private individuals. The public should be made aware of the potential impacts of climate change upon park species, ecosystems, and features, and what adaptations may be required. Visitors should learn what they can do, in parks, at home, and at work, to assist in the mitigation of climate change through direct actions or by spreading the word to their friends and family. Actions by park agencies can encompass the inclusion of climate change messages in interpretation programs, posting a climate change summary document on Internet sites, and working with education authorities, other departments, governments, and non-governmental groups to develop and deliver climate change and protected area information to children and adults alike. Parks should collaborate with intergovernmental, non-governmental, and international bodies to promote national and global strategies for protected areas to adapt to climate change.

### Leading by example

**Reduce greenhouse gas emissions.** Greenhouse gases (GHGs), including carbon dioxide, nitrous oxide, and methane, are generated primarily by the consumption of fossil fuels in the operation of vehicles and the heating of buildings. Many countries, including Canada, have agreed to reduce their GHG emissions under the Kyoto Protocol. Park agencies can use their favorable public presence to lead the way in minimizing building energy consumption through design and operational practices, reducing their fleet and switching to more energy efficient vehicles, fuel switching and taking advantage of emerging technologies.

**Promote personal action plans for staff.** Employees and volunteers can play a vital role in the community through their personal actions at home and in their neighborhoods. Employers can help by providing public transit passes rather than subsidizing parking; extending incentives for car pooling, cycle commuting, and telecommuting; and promoting energy use reductions in homes and lifestyle choices.

**Adapt natural region representation strategy.** Many countries have followed Parks Canada's lead in using a natural region representation approach to the development of a network of national parks. Natural regions are typically based on a combination of physiography and dominant vegetation. While physiography remains largely constant in anything less then geological time, vegetation is dynamic and successions and processes have changed significantly even in living memory. Climate change will accelerate this process to the extent that natural successions at most parks will evolve over decades at most. Parks will no longer be able to truly represent a past biology.

Nevertheless, there is great value in a region-based approach to park establishment. It assures a distribution of parks across many landscapes and ecotones, itself one of the best ways to protect biodiversity under climate change. A rational network basis for a park system also deflects the strains of short- and mid-term demands for land protection when there is already a park representing a specific area. Therefore, existing polygons or map entities of natural regions should be retained, but their descriptions may have to be changed to reflect the dynamics of present and future climate. New park locations and boundaries should be established in ways that maximize site diversity and landscape porosity.

**Address climate change adaptation in park management plans.** Management plans encapsulate park objectives and the activities that help to achieve them. These plans are also an accountability tool for performance reporting. What is not in a plan tends to be considered unimportant. Given the enduring nature of parks and the long-term implications of climate change, adaptation should be addressed in management plans. For example, park purposes can be modified to protect processes and biodiversity rather than specific biomes and species, and management planning guidelines can direct that park purpose statements be tolerant of biotic changes resulting from natural and anthropogenic climate change. Boundaries can be reviewed to seek opportunities for changes that would favor the protection and maintenance of ecological integrity. An example might include seeking higher-elevation lands to protect Alpine tundra species. Management plans should endorse research and monitoring of ecosystem indicators sensitive to climate change. Ecosystem restoration projects can be directed to take future climates and vegetation successions into account.

**Report on natural and management adaptations to climate change.** Whether reactive or adaptive, an integral part of management is the monitoring of progress towards a goal, and then to assess results and modify future actions accordingly. Documenting these processes is essential to full debate and on-going support, be it by legislators, policy analysts, or the general public. The use of a regular report series is the best guarantee of systematic publishing, dissemination, and readership. This does not have to be in a scientific journal or series. Annual reports, quintennial or decennial state-of-park reports, or in-house occasional papers are often more appropriate to the audience and purpose. Ecosystem managers should select indicators of climate change impact for their park and its natural region, develop protocols and implement monitoring, and collaborate with regional partners to report the ecological impacts of climate change to the public and to policymakers.

### Active ecosystem management

**Eliminate or mitigate non-climate *in situ* threats.** The growing body of research on interactions between climate and non-climate stresses suggests that responses are synergistic (e.g., Schindler 2001). To maintain or rebuild ecosystem resilience, one must therefore reduce the number and/or magnitude of insults faced by an ecosystem. Fortunately, many stressors are more locally and regionally 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. In a forest ecosystem, it may mean preventing fragmentation by access roads. It may mean protecting alpine tundra from ski resort development. It may mean limiting harmful grazing practices in grasslands. None of these tasks are easy, but they are approachable on a local level and they can increase the overall resilience of ecosystems (Hansen et al. 2003, 11). Many protected areas are already pursuing threat reduction and sustainable regional ecosystems through conservation partnerships with land management agencies. This is also the right thing to do to blunt the edge of climate change. As noted above under stakeholder awareness, parks should promote regional ecosystem conservation measures and partnerships that maintain or build porous landscapes through which assemblages of species can migrate in response to climate change. A good network of large protected areas at the core of biosphere reserves may be wild nature's best climate change "shock absorber."

**Use adaptive management.** Given uncertainty about the exact nature of ecosystem impacts of and responses to climate change, effective management will require a responsive and flexible approach. Adaptive management is a methodology in which one can proceed with only limited or uncertain knowledge. It is an approach whereby an intervention is conducted as if it were a scientific experiment (Nudds 1998), with measurable, time-bound targets set in advance (policy = hypotheses), careful measurement of results as things happen (intervention = experiment), and approaches adjusted as new information becomes available (reporting, analysis, re-setting hypotheses). Park agencies should follow adaptive management guidelines for impact abatements such as species protection, translocation of slow-spreading key species, or retardation of fast-spreading pioneers. An adaptive management approach is particularly important in ecosystem restoration in an uncertain, changeable climate.

**Use climate change research results.** There are many climate and vegetation change models, and many of their results are available on the web or in journals and government reports. However, most are global or national in scale. As well, there is a steep learning curve required to properly interpret ensembles of climate change scenarios and the assumptions and uncertainties involved. It is not enough to have good primary science. There must be secondary, or derived, products that digest and customize this knowledge for interdisciplinary professionals. Without these, good science collects dust. Protected area agencies should commission secondary studies that translate this vast body of science to regional and park-specific data sets that place-relevant, user-friendly information into the hands of ecosystem managers. Parks Canada has done this through the work of Scott (2003), which resulted in spreadsheets of annual, seasonal, and monthly temperature and precipitation data for twelve general circulation model–emission scenario combinations for three periods in the 21st century for each Canadian national park. The work is accompanied by narrative projections of physical and biotic changes, again for each park. By having access to customized climate change and impacts information, park managers now recognize climate change as a major ecosystem stressor, and can build monitoring frameworks with climate change indicators in mind.

As well as providing scientific syntheses, park managers need the tools to use climate change information in their decision-making processes. Climate change guidelines for environmental assessment are now available in Canada, covering projects that either have the potential to emit greenhouse gases, or projects that will be impacted by climate change (CEAA 2003). Similarly, there is probably a need for guidelines for modeling ecosystem restorations and infrastructure development.

**Adjust park boundaries as needed for climate change adaptation.** Changes in climate will lead to changes in habitat and species survival. Some vegetation species would have to migrate hundreds of kilometers to follow climate, although this is unlikely to happen depending on factors such as seed dispersal method, topography, soil type, and fragmentation by land uses. Other species might find a new home a short distance away. For the latter it may be possible to adjust park boundaries to capture the anticipated movement of critical habitats and species. Park boundaries could be aligned to accommodate transition zones where large changes of climate, habitat, and species distribution are expected to occur over small distances in relation to park size.

### Research

**Understand the impact of past and future climate change.** Decision-makers and park visitors alike will benefit from the lessons to be learned from a comprehensive knowledge of Holocene landscape changes. Such knowledge helps to provide an understanding of the changeable nature of climate even in historical times, and will provide some measure of nature's ability to adapt autonomously. The impacts of climate change on natural processes and visitor activities should also be researched thoroughly before committing to expensive and irreversible ecosystem restorations or visitor infrastructure development. Each park should be rated for its sensitivity to a 3x$CO_2$ world. Of course, the development of a research agenda should not be an excuse for postponing early action on awareness, leadership, and active ecosystem management where the "no regrets" principle applies.

**Identify values at risk of being significantly impacted by climate change.** Ecosystems have too many components to understand and track them all, considering our poor understanding of most ecosystems, budget constraints and the short time frames typically imposed on analysts and managers. The concept of valued ecosystem component (VEC) provides a means to set management goals without becoming bogged down in the minutiae of all species, all minerals, and so forth. A VEC is defined as an "environmental attribute considered to be important for decision-making" (Munn 2002). VECs are usually tangible things, like a keystone species or iconic vista, to which indicators for monitoring are closely tied.

Each park should identify a limited suite of VECs that are sensitive to climate change, such as species at the margins of their climatic range, species with limited or excessive abilities to migrate, and physical features such as permafrost environments and ombrotrophic wetlands. Barriers to migration should be identified, such as fragmented habitats and restricted vertical migration paths.

**Support downscaled climate modeling.** Current climate change scenarios use global models with very coarse resolution of major topographic features. Much research is in progress to develop climate change models that fit regional scales and take into account, for example, great lakes and bays. Ecosystem managers should be prepared to support such research where it would lead to more detailed scenarios for their region, and hopefully to scenarios that reflect local topography and vegetation with more certainty and precision.

### Monitoring

**Promote parks as long-term integrated monitoring sites.** Climate change will bring unexpected combinations of direct impacts, secondary effects, and new associations of processes, features, and species. Hence national parks should be managed as integrated ecosystems, not for one particular VEC. Integrated monitoring is a complementary management and reporting tool that can reveal unexpected linkages between ecosystem components and the drivers of environmental change. The prime attraction of integrated monitoring is its ability to mine existing data to spot emerging influences and explain responses. Each stress does not need its own unique set of indicators. Often, several stresses can be tracked from a limited but well-selected ensemble of indicators. Integrated monitoring also fosters partnerships in which many agencies share costs while receiving benefits greater than the sum of the inputs.

**Data gathering and reporting actions.** Each park should have long-term climate and climate change indicator data. These data should be reported at the park level and regional or national levels.

### What not to do?

**Do not move parks to anticipated biomes.** While some parks might benefit from local boundary adjustments to protect ecosystems and habitats at risk from climate change, as noted above the general notion of dynamic parks must be rejected on policy grounds, as opening the door to any other reason to move a park, e.g., to extract minerals or fiber. The notion must also be rejected on the pragmatic basis that few natural areas remain for new park establishment within existing or future regions that already have national park representation. Rather, the present parks are often all that is left to provide a haven for nature during a time of great change. Thirdly, park establishment is a lengthy process with no guarantee of success. In sum, the presence of a well-distributed system of protected areas is one of society's best adaptations to climate change. Even if one protected area loses certain species and associations, species will have their best chance of finding new homes in a well-managed, well-distributed, well-connected, and properly sized network.

**Do not use parks to buffer or mitigate other impacts.** Parks are not an insurance policy against negligence or mismanagement of natural hazards and natural resource supply. The restoration, protection, and maintenance of natural systems precludes the manipulation of an ecosystem to an artificial condition in order to counter an artificial threat. Some of these ecosystem services may come about with the maintenance and restoration of ecological integrity, but parks should not be manipulated for flood protection, water supply, or carbon sequestration, for example. As with the idea of moving parks, this would open the door to the commercialization of natural resources in parks.

**Do not modify natural region boundaries to fit future biomes.** Many nations use, or are considering the use of, a natural region representation approach to park establishment. This system has served Canada well since its adoption by the federal cabinet in 1976. The constancy of the number of regions and their boundaries has been a cornerstone of the park system plan since that time. It has allowed Parks Canada to pursue a consistent course towards completing a pan-Canadian system of national parks without being sidetracked by interest groups or ministerial lobbying to add another park here or there to satisfy vested local interests. Upon the publication of the ecozone map of Canada in the early 1980s, the issue of natural region boundary change was addressed and rejected. Even though the ecozone map is a later product, is scientifically more defensible and was the product of federal, provincial, and territorial agreement, if the precedent were to be set that the natural regions policy could be changed, then there could be no end to further pragmatic modifications of regions.

All climate scenarios are based on a series of assumptions about future emissions, the physics and chemistry of the atmosphere, and geographical simplifications to allow world models to operate on today's supercomputers. Vegetation response is likewise based on a series of modeling and plant succession assumptions. While these collectively represent the best science today, and show a great deal of convergence in their general findings, the placement of region boundaries is by definition notional and subject to change as climate and vegetation models improve, and as the world moves forward into updated real emission inventories rather than scenarios. To change natural region boundaries on this basis would open up a never-ending process, and create a unrealistic setting for park feasibility studies and establishment negotiations that already can take years or decades.

## Conclusions

However well protected areas are managed, they cannot by themselves have much direct effect on greenhouse gas levels. Rather, a good network of protected areas free of other stresses is one of society's and nature's best adaptations to climate change. They can also play a vital communications role in influencing visitors and the concerned public. These two—good parks and good communications—in turn require well-researched and -monitored climate change impact indicators as the basis for adaptive ecosystem management, accountability, and reporting systems, and for interpretive, outreach, and education programs. House-in-order programs complement the messages that governments should be sending to their peoples. Research on the synergy between climate change and other stressors, such as habitat fragmentation and air pollution, can provide the knowledge to guide the mitigation of local and regional stressors, thereby restoring some of the natural resilience of ecosystems and wild species.

Regardless of the debate over climate-forcing mechanisms and who does what to whom, we are more aware than ever that we are entering an era of rapid climate change, recent and future, and we had better get used to it. Protected areas should play a leadership role to ensure that wild nature also enjoys the ride.


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