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ATMOSPHERIC CHANGE AND BIODIVERSITY:

FORMULATING A CANADIAN SCIENCE AGENDA

Summary Report of a Workshop
R.E. Munn, Editor

Sponsored by:

Environment Canada

Atmospheric Environment Service,
Biodiversity and Conservation Policy & Planning Directorate,
Ecological Monitoring Coordinating Office,
Environmental Conservation Branch.

Institute for Environmental Studies,
University of Toronto
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Foreword

At the UNCED Rio Conference in 1992, a Convention on Biological Diversity was signed by 156 nations and the European Union. The Convention entered into force as a legally binding document in December 1993. In 1994, Canada established a Biodiversity Convention Office, produced a Science Assessment of Canadian Biodiversity, and subsequently developed a National Biodiversity Strategy in 1995. Although all of these initiatives recognized climate and other atmospheric issues as important environmental stressors on biodiversity, there have been few occasions when the effect of atmospheric changes on biodiversity was discussed.

In Toronto, February 26-29, 1996, a Workshop was held on the topic "Atmospheric Change and Biodiversity: Formulating a Canadian Science Agenda". The Workshop was organized and co-sponsored by the Institute for Environmental Studies (IES), University of Toronto. This summary includes some background information on the Workshop (Chapter 1), an overview of the plenary presentations (Chapter 2), a paper on UNEP's role in linking atmospheric change and biodiversity by UNEP Program Officer A. Alusa (Chapter 3), reports of the five working groups (Chapter 4), a summary of the final panel discussion (Chapter 5) and a synthesis of the main conclusions (Chapter 6). A full version of the Workshop proceedings will be published by Kluwer Academic Publishers in 1997 as a special issue of the journal "Environmental Monitoring and Assessment", and as IES Monograph No. 13.

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R.E. (Ted) Munn, Editor

EXECUTIVE SUMMARY

Workshop focus

Over the last decade, ATMOSPHERIC CHANGE and BIODIVERSITY have become important national and international issues. However, the linkages between the two issues are not often considered. What would be the effects of climate warming, stratospheric ozone depletion or acidic deposition, for example, on biodiversity? The Workshop held in Toronto February 26-29, 1996, ATMOSPHERIC CHANGE AND BIODIVERSITY: FORMULATING A CANADIAN SCIENCE AGENDA, was therefore particularly interesting and relevant. Although some felt that such an event would be premature, there was certainly consensus by the end of the Workshop that to promote studies on the effects of atmospheric change on biodiversity, cross-linkages had to be established as soon as possible between atmospheric scientists and the biological community. This Workshop was successful in setting a course forward for collaboration, even if some of the details remain to be worked out. That this is an urgent task is underscored by comments from many of the ecologists present that there is an accelerating biodiversity crisis in Canada and globally. This will be exacerbated by the atmospheric changes expected in coming decades.

Before summarising the main recommendations of the Workshop, it is worth emphasizing that assessment of the effects of atmospheric change on biodiversity is a difficult multi-factorial problem. This is largely because biodiversity is affected by many factors, which can be subdivided into two groups:

> **FACTORS OF NATURAL ORIGIN**: natural variability in environmental stresses, particularly rare events (droughts, floods, forest fires, avalanches, etc.)
>
> **FACTORS OF HUMAN ORIGIN**: destruction of habitats and corridors (through urbanization, hydrological development, drainage of wetlands, deforestation, agro-engineering, road construction, etc.); accidental introduction of exotic species; over-harvesting of fish and game; etc.

For an ecosystem subjected to several stresses, increasing one of the atmospheric ones may cause a much greater response than if imposed alone. In general, atmospheric change is likely to be at least a contributing cause in many cases of biodiversity loss.

General recommendations

1. Three major global environmental issues are inter-related: biodiversity, climate change and stratospheric ozone depletion, each having its own intergovernmental framework convention or protocol. Every effort should be made to establish, insofar as possible, mutually supportive science programs with respect to the three issues in terms of monitoring, research and assessment, and of policy formulation - at both the international and the national levels.

2. The various options for responding to the effects of atmospheric change on biodiversity should be laid out in an informed and publicly accessible fashion. The information provided to stakeholders and the public should include for each alternative: the reasoning; reasonable cost estimates and potential benefits; the ethical underpinnings; and the expected outcomes.

3. Closer collaboration should be fostered between the community studying atmospheric change and the community studying biodiversity. Some ways in which this might be accomplished include:

- Establishment of a joint working party;
- Sponsorship of scientific meetings (in conjunction with national meetings of EMAN or one of the relevant scientific societies);

- Preparation of "Fact Sheets", by Environment Canada, for example;
- Publication of news releases or scientific papers in appropriate news letters or scientific journals.

Interdisciplinary collaboration should be expanded to include engineering, the health sciences, industry, and the main social sciences; and the relevant scientific societies, NGOs, industrial bodies and federal and provincial agencies should be involved.

4. When studying the effects of atmospheric change on biodiversity, more attention should be given to the concepts of *ecosystem integrity*, *self-organizing non-equilibrium systems*, *the ecosystem approach* and *uncertainty*. These concepts provide a useful framework for understanding the effects of atmospheric change on biodiversity, and thus provide a valuable policy tool.

5. There is an urgent need to establish research priorities with respect to studies of the effects of atmospheric change on biodiversity. One tool that would assist in this task is that of multi-issue science assessments.

6. There is also a more general need to undertake assessments of risks to Canadian biodiversity from all kinds of natural and human-induced causes.

Recommendations concerning research and monitoring programs

1. The Ecological Monitoring and Assessment Network (EMAN) program is endorsed as a foundation for future studies on biodiversity and atmospheric change. At the present time, insufficient effort is being given to field studies of biodiversity in Canada and elsewhere. In designing new programs, care must be taken to include information that will be useful for hypothesis testing.

2. Research should be supported into:

   (a) the development of ecological indicators of the responses of biodiversity and ecosystem functions to atmospheric change. Some approaches that should be tested are:

      (1) The use of umbrella species that integrate complex information within communities and/or landscapes;
      (2) Functional indicators, e.g., decomposers, nitrogen fixers;
      (3) Composite indicators of ecological integrity;
      (4) Proxy indicators, e.g., paleo indicators;
      (5) Downscaling (for atmospheric change);
      (6) Upward long-wave radiation from terrestrial ecosystems (for biodiversity);
      (7) Sudden changes in ecosystem behaviour once a critical threshold in atmospheric change is reached; and
      (8) Inclusion of traditional local knowledge of both atmospheric and biodiversity changes in former times.

   (b) the causes and consequences of losses of biodiversity and degradation of ecological functions. This should be undertaken not only at intensive EMAN research facilities but also over spatial grids, particularly along gradients in atmospheric conditions (e.g., across latitudinal and altitudinal tree-lines, across prairie-forest ecotones, and inland from coasts).

   (c) the development of improved models of relationships between atmospheric change and losses of biodiversity and degradation of ecosystem functions.

3. More emphasis should be placed on landscape-scale studies of the effects of atmospheric change on biodiversity. This is the scale where human affairs are conducted, and where the effects of global change on terrestrial ecosystems are studied.

4. Satellite detection of biodiversity changes at the landscape level should be given increased priority by the biodiversity/atmospheric change community. Satellites can provide long-term landscape-scale ecological data on a scale of 1km x 1km. Such information is invaluable for long-term studies of fragmentation of ecosystems, loss of corridors, movements of ecotones and degradation of habitats. The Canada Centre for Remote Sensing's provision of 10-day composite data on various ecological indicators should be continued over the long term, with periodic meetings with users to review progress and plan future activities.

5. Special emphasis should be given to biodiversity "hotspots" in Canada, i.e., biomes and sectors most at risk from atmospheric change. See Table 4.1, pg.35, Table 4.2, pg.36 and the box on pg, 37. Special attention should be given to relict terrestrial and freshwater habitats in the Mixedwood Plains Ecozone of Southern Ontario where human development seriously threatens many species and makes them particularly vulnerable to atmospheric change.

6. Protected areas: More emphasis should be placed on linking conservation, protected areas, bioregions (the landscapes surrounding protected areas) and climate change. In particular:

a) One of the objectives should be the determination of those species and ecosystems in protected areas that would be particularly stressed by climate change (See Fig. 4.1, p. 26).

b) Care should be taken to ensure that the surrounding bioregion is not subjected to ecologically incompatible land uses.

c) A protected area should be the core of a much larger bioregion research program, the broad objective being to maintain biological diversity in both the protected area and the surrounding bioregion in an era of climate change.

7. Atmospheric and biodiversity changes are no respectors of jurisdictional boundaries. The Canadian biodiversity science agenda should include studies of potential changes in both national and international species migrations along corridors, flyways and staging grounds for migrating species in an era of a warmer climate. This should also include studies of potential pathways for the invasion of undesirable alien species, and the design of early warning monitoring systems.

8. To assist social scientists in participating more meaningfully in studies of atmospheric change - biodiversity change, an inventory should be prepared of potential scenarios for atmospheric change possible in the next 50 years, together with the likely consequences for biodiversity, and the socioeconomic implications.

Policy recommendations

1. More emphasis should be given to the fact that biodiversity policy will often involve trade-offs between protection of species and of ecosystem integrity. [The role of science is to illuminate these trade-offs and consequences.]

2. A more careful exploration is required of what we value/what is valuable in the atmospheric change/biodiversity debate. [Do we wish to protect species, ecosystems, functionality, productivity or human well-being? The role of science is to illuminate the consequences of our value systems.]

3. A broader definition/mandate for managing biodiversity should be developed, with a move away from an overly preservationist view.

4. Departmental guidelines on sustainability should be expanded to include guidelines on biodiversity and atmospheric change. In particular, practical manuals should be prepared on how to include biodiversity considerations in cumulative environmental assessments.

5. Natural scientists should work with social scientists to connect natural adaptability/resilience/productivity, particularly through the use of the ecosystem approach, to equivalent socioeconomic conditions.

6. Efforts should be made to improve the response capabilities of those bureaucratic and political systems with divided jurisdictions and overlapping boundaries, which limit capacities for dealing with the atmospheric change/biodiversity issue.

7. Practical guidelines should be developed on how to include biodiversity considerations in environmental assessments and cumulative environmental assessments.

Three questions

(1) *Can biodiversity change give an integrated picture of atmospheric change, including an early-warning capacity?* In some cases, the answer is yes. For example, an appropriately designed monitoring program for climate could focus on community-level biodiversity changes occurring at climatically determined ecotones, such as latitudinal or altitudinal tree-lines, or prairie-forest ecotones.

(2) *Can atmospheric change provide an early warning of impending changes in biodiversity or ecosystem function?* In some cases, the answer is yes. For example, an appropriately designed monitoring program for climate could focus on situations in which climatic variables are known to be the primary controlling factors of biodiversity elements or ecosystem functions.

(3) *Is the understanding of known or potential linkages of atmospheric change and losses of biodiversity sufficiently well-founded to establish policies towards avoidance or mitigation of damages?* Some of the relationships are sufficiently understood to establish policy and implement actions. This is particularly true of acidifying deposition from the atmosphere, toxic gases, and anthropogenic intensification of the greenhouse effect. This is also true, but to a lesser degree, of depletion of stratospheric ozone and deposition of trace toxics from the atmosphere. The cumulative effects of environmental stressors are not yet well understood.

A Canadian science agenda on the effects of atmospheric change on biodiversity

Chapter 6 contains the elements of a science agenda with respect to the effects of atmospheric change on biodiversity.

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Chapter 1: PURPOSE OF THE WORKSHOP AND BACKGROUND INFORMATION

1.1. Workshop Objectives

A workshop on atmospheric change and biodiversity in Canada took place 26-29 February, 1996 in Toronto. The main Workshop objective was to formulate a Canadian science agenda on the effects of atmospheric change on biodiversity. Some of the elements have already been identified in the Canadian Biodiversity Strategy (Env. Canada, 1994), the Science Assessment on Biodiversity in Canada (Env. Canada, 1994) and elsewhere. But the pieces needed to be brought together.

Other objectives of the Workshop were:

1. To review and update existing inventories (see, for example, Env. Canada, 1994; EMAN, 1995; CGCP, 1995) of past and present activities that could support a national Canadian program on atmospheric change and biodiversity from the point of view of the natural and social sciences, and of the policy response community;
2. To recommend mechanisms that will foster the sharing and exchange of information (data, models, assessments, policy initiatives, etc.) relating to biodiversity and atmospheric change in Canada;
3. To propose programs for scientific training and exchanges that will enhance the national effort on biodiversity and atmospheric change.

1.2. Background Information on Biodiversity

Bio**logical **diversity (biodiversity) is an attribute or property of natural systems. Biodiversity represents the total richness of biological variation. Biodiversity is commonly considered in a hierarchical manner, with elements that range from (1) genetic variation within and among populations, (2) richness and abundance of species, (3) variations of communities, and (4) the spatial patterns and temporal dynamics of all of these elements on landscapes and seascapes.

Biodiversity can be viewed from several perspectives, all of which are valid.

1. **The ethical perspective**: It is often argued that it is ethically wrong to permit species extinctions although in some cases, such as the elimination of smallpox, this is not necessarily so. What, then, are the criteria for protecting or deliberately modifying biodiversity?
2. **The economic perspective**: Many species have economic value, e.g., as drugs to combat human illness, for plant and animal breeding, for genetic engineering and for industrial applications, including bioremediation. Because the economic value of some species has not yet been recognized, it is wrong in general to encourage policies that may lead to species extinctions.
3. **The ecosystem-functioning perspective**: Biodiversity provides ecological goods and services that benefit humans and other species. Some elements of biodiversity are varieties or species that humans cultivate as resources, or exploit from semi-natural or natural habitats. These represent potentially renewable, natural resources. An ecosystem encompasses many species, which interact in complex ways. Removal of a particular species (through over-harvesting or destruction of habitats, for example), or addition of exotic species (biological invasions) may have no apparent effect, or in extreme cases may cause an ecosystem to change radically.

Removal of the otter along parts of the northeastern rim of the Pacific Ocean caused a population explosion in their prey (herbivorous sea urchins), and led to overgrazing of the kelp. Coastal zones so affected have become biological deserts.

Duggins *et al*. (1989); Estes and Palmisano (1974); Estes *et al*. (1978)

For these and other reasons, international action has been taken over the last decade to seek consensus on a Convention on Biological Diversity. At the UNCED Rio Conference, 156 nations and the European Union signed the convention, and it entered into force as a legally binding document on Dec. 29, 1993.[1] The Convention focuses on three main themes:

- conservation of biodiversity;
- sustainable use of biological resources; and
- sharing the benefits of biodiversity.

In Canada, this has led to the development of a Canadian Biodiversity Strategy, which calls for (Lazar, 1995):

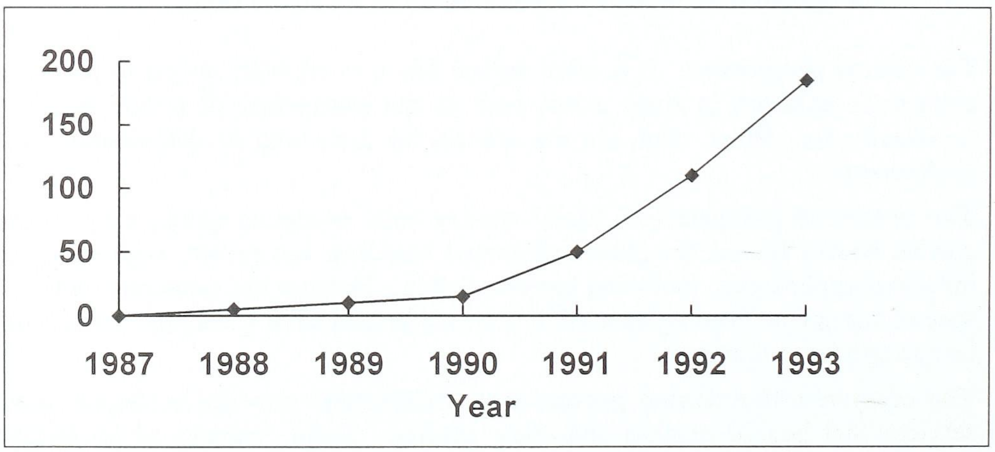
- integrated decision making on an ecosystem basis;
- stewardship of all the landscape (not just protected areas); and
- catalyzing individual responsibilities.

Implicit in both the intergovernmental and the Canadian documents is the idea that in order to conserve biodiversity, it is important to protect habitats and important transit corridors for species that migrate.

In 1994, Environment Canada produced a science assessment of Canadian biodiversity (Env. Canada, 1994), which provides a valuable overview, including a chapter on biodiversity and atmospheric change.

As can be seen in Figure 1.1, the number of published papers in the scientific literature has been growing rapidly since 1990.

Fig. 1.1 Number of papers with "biodiversity" in the title (1993 includes only Jan.-March data) *adapted from J. McNeely (paper presented at this Workshop)*



[1] The United Nations (1995) subsequently established an international Biodiversity Secretariat in Montreal with Calestous Juma as Director.

Humans have already caused enormous losses of biodiversity in all parts of the world, largely through extinction and endangerment of numerous varieties, species, and natural ecosystems. Unless there are substantial changes in the ways humans affect ecosystems, ecologists predict tremendously larger losses of biodiversity in the near future. In all places and regions, indigenous biodiversity is most at risk.[2]

The most important threats to biodiversity are associated with (1) extensive habitat losses through the ecological effects of disturbance, introduced species, and conversions of natural ecosystems into managed systems, and (2) commercial over-exploitation of biodiversity resources. Biodiversity is also significantly threatened over the long term by ecological changes associated with changes in atmospheric conditions.

It is important to recognize that major elements of Canadian biodiversity are not well described, and the specific factors that are putting most elements of biodiversity at risk are not well known. Some positive actions are being taken to deal with this crisis of information and knowledge, but these are not developing as quickly as required, considering the depth of the biodiversity crisis. For example:

(a) Conservation Data Centres (CDCs) are facilities designed to collect, analyze, and portray data on species and communities, using a GIS-based system developed by The Nature Conservancy (U.S.A.). A network of CDCs has been established in all U.S. states and in some countries in Latin America. In Canada, The Nature Conservancy of Canada, in partnership with provincial and federal governments, and others, is attempting to establish a network of Conservation Data Centres, but progress has been slow, and operating budgets of several centres are at risk.

(b) Canada has a process for the designation of endangered species, and the development of recovery plans, known as COSEWIC (**Com**mittee on the **S**tatus of **E**ndangered **W**ildlife **i**n **C**anada). This multi- sectoral group has designated several hundred Canadian taxa, but there is a large backlog of species that has not yet been considered, and progress is slow in the development and implementation of recovery plans.

(c) A critical problem in the identification and study of Canadian biodiversity relates to the extreme scarcity of taxonomic specialists capable of identifying many groups. This unfortunate circumstance reflect changes in priorities in the funding of this aspect of biological research, and in the training of specialists at universities.

(d) Several programs of integrated monitoring and research into the causes and consequences of environmental change are being designed and implemented, most importantly the emerging Ecological Monitoring and Assessment Network (EMAN). These are essential initiatives, but they are not yet sufficiently supported. It is particularly notable in this regard that Canada's most famous site for monitoring and research of environmental and ecological changes in freshwater ecosystems, the Experimental Lakes Area (ELA) in north-western Ontario, is severely threatened by budgetary cutbacks. Considering the extreme need for the sorts of scientific data and knowledge provided by sites like ELA and networks like EMAN, the lack of enthusiastic support for these initiatives is extraordinary.

1.3. Background Information on the Atmospheric Stressors[3]

The atmospheric environmental stresses, present and future, that could affect the current state of biodiversity in Canada include climate change, stratospheric ozone depletion and increased UV-

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[2] *This paragraph and the remainder of Section 1.2 were contributed by B. Freedman.*

[3] *Contributed by A. Maarouf*

B radiation, acidic deposition, increased levels of ground-level ozone and other photochemical pollution (SMOG), suspended particulate matter, and hazardous air pollutants.

Climatic Change: Increases in greenhouse gas concentrations in recent years have lead to a positive radiative forcing of climate, tending to warm the Earth's surface and to produce other changes in climate. The Intergovernmental Panel on Climate Change (IPCC) Second Assessment Report (1996) concludes that the balance of evidence suggests "a detectable human influence on global climate", and recent years have been among the warmest since at least 1860. Global climate models predict a global warming of between 1.0C and 3.5C by 2100.

Stratospheric Ozone Depletion: Ozone is continuously and simultaneously being formed and destroyed by natural processes in the stratosphere between 10 and 50 km. In recent years the stratosphere has been perturbed by a number of synthetic organic chemicals, including chlorofluorocarbons (CFCs), halons and other chemically similar substances, which are stable, long-lived chemicals in the troposphere but eventually reach the stratosphere where they participate in a number of complex reactions leading to the breakdown of ozone. As a result, the amount of ozone in the stratosphere has diminished. Ozone depletion is now observed in many parts of the world, causing an increase in solar UV-B radiation reaching the Earth's surface. Excess UV-B exposure leads to an increase in skin cancer and other effects on humans and ecosystems.

Acidic deposition: Sulphur and nitrogen oxides from smelters and fossil-fuel power stations may travel long distances before being washed out by precipitation or being deposited directly on vegetation and other surfaces. The effects of acidic deposition have been widely studied, particularly with respect to lakes, vegetation, buildings and groundwater.

SMOG: This term refers to a harmful mixture of gases primarily caused by the burning of fossil fuels. The main component of smog in many Canadian cities is ground-level ozone (O_3). Other components of smog, such as sulphur oxides (SOx) and peroxyacetyl nitrate (PAN), occur in small quantities as compared with O_3. Ozone occurs as a result of a reaction between nitrogen oxides (NOx) and oxygen in the air. However, human-created NOx and volatile organic compounds (VOCs) accelerate ozone formation, resulting in excessive amounts of ground-level ozone. Because smog-forming reactions depend on temperature and sunlight, smog problems are particularly acute on hot, sunny summer days.

Suspended Particulate Matter: This term includes particles and very small droplets (aerosols). Natural particles and aerosols include sea salt, soil dust, biomass burning, terrestrial and marine biogenic emissions and volcanic eruptions. Anthropogenic aerosols include sulphates, nitrates, black carbon (soot), organics, the products of human-induced biomass burning and wind-blown dust. Most sources of anthropogenic particles and aerosols are found in the lower troposphere (below 2 km), while aerosol particles from volcanic eruptions are found in the upper troposphere and lower stratosphere. Aerosols undergo chemical and physical transformation in the atmosphere, especially within clouds, and are removed largely by precipitation. Consequently, aerosols in the lower troposphere have residence times of typically a few days, while aerosols in the stratosphere may remain for many months (IPCC, 1996).

Hazardous Air Pollutants (HAPs): HAPs are defined as chemicals in the atmosphere that, in sufficient concentrations, may have adverse effects on the health of humans and other animal species, and may cause damage to ecological and societal systems such as forests, agricultural crops and building material. HAPs come from many man-made and natural sources, and include a wide range of pollutants, in addition to those mentioned above under SMOG and suspended particulate matter, e.g. pesticides, radionuclides, etc.

The above atmospheric stresses on ecosystems are known to be inter-related (Munn, 1995), and they sometimes interact to cause negative as well as some beneficial effects on ecosystems, and thus on biodiversity. As examples: (1) Sulphate aerosols cause acidic deposition while at the same time producing slight climate cooling; (2) In a warmer climate, episodes of ground-level ozone and other pollutants are likely to be more intense and more frequent.

1.4. Background Information on the Potential Effects of Atmospheric Change on Biodiversity in Canada[4]

1.4.1. General Remarks

A number of specialists postulate that the success of evolutionary processes, and thus of sustainability of an ecosystem to long-term atmospheric change, depend on the system's biodiversity. For example, a reduction in the number of component parts of the ecosystem or in its gene pool limits the potential of the system to adapt to atmospheric change.

In the 21st century, climate change could cause a shift northward of the ranges of many native biological species, and some exotic species could invade Canada from the south. In addition to ecosystems, and even large biomes, moving physically, there is the possibility that the composition of these systems, both natural and managed ones, could change significantly. The net result would generally be detrimental, both from an ecological and an economic point of view. Because climate warming is expected to be greater in northern latitudes than in the tropics, Canadian scientists and policy- makers are giving higher priority to the climate change-biodiversity issue than are those in more southerly countries. Of course, other atmospheric stresses are also expected to increase in the next 50 years, e.g., deposition of nitrates, and intensity of ozone episodes.

A question of special significance is that because species are naturally adapted to a certain degree of variability, they may not begin their migration or adaptation at the earliest stage. However, all ecosystems have environmental threshold levels which if exceeded will permanently alter them (Gates, 1993). It is not the whole ecosystem that adapts to climate change; species respond individually to both climate as well as to other atmospheric issues such as acid rain, UV-B radiation and smog. It is when species start to respond to change that an ecosystem may enter a new state. This occurs, for example, when the chain of prey and predators is broken and new 'exotic' species move into a system.

Those species most at risk due to climate change (Peters, 1992) are:

- Peripheral populations of plants or animals that are at the contracting edge of a species range.
- Geographically localized species. Many currently endangered species exist in extremely limited habitats.
- Highly specialized species. Many species have, for example, a close association with only one other species, like the Kirtland's warbler that nests only in jackpines (Aird, 1990)
- Poor dispersers. Many trees have heavy seeds which may not disperse far. Some forest birds will not cross even a small patch of open land to another piece of forest.
- Montane and alpine communities. Populations of plants and animals on mountains may literally be pushed off the mountain tops as the climate warms.

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[4] *Contributed by N. Mayer*

- Arctic communities. Climate warming is expected to be greatest at high latitudes. Therefore, organisms of these regions may be subjected to the largest and most rapid change.
- Coastal communities. Because sea level is expected to rise, many shoreline communities may be inundated.

An additional risk in montane, alpine and arctic communities is the impact of increasing UV-B due to stratospheric ozone depletion. Already there is some evidence of lichen damage in recent years at a Danish monitoring station in Northern Greenland (Johnsen and Heide-Jørgensen, 1993).

1.4.2. Canadian Systems: A General Overview

Canada is a large and diverse country with 177 ecoregions, within 15 ecozones. A preliminary study indicates that 7% of Canada's biodiversity is at high risk, and 25% is at some risk (Environment Canada, 1994). As the atmosphere changes, each part of Canada will face different challenges and situations. Some examples are given below.

Forest Ecosystems: The general consensus is that the anticipated rate of forest ecosystem movement due to climate change will be about 200 km northwards in 50 yrs (Peters, 1992). It is important to note that a rise in altitude of 50m is equivalent to a movement northward of 200 km (Peters, 1992). These latitudinal and altitudinal shifts may alleviate some of the stress from climate change on Canadian forests; however other factors such as soil conditions and precipitation must also be considered. It has been estimated that the southern boundary of the Canadian Boreal Forest may shift 470-920 km as a result of a doubling of greenhouse gases (Wheaton et al., 1987), with net losses of 100 million hectare due to atmospheric change (Sargent, 1988). As noted earlier, climate change is anticipated to be greater in the higher latitudes; therefore the northern frontiers of these ecosystems are likely to be affected first.

Forest fires are expected to increase across Canada due to climate change. It has been estimated that in the Mackenzie Basin the rate of annual burn may increase by almost 50% (Landhäusser and Wein, 1994). Two main issues arise from an increase in forest fires; the first is a positive feedback due to the CO_2 released from burning. The second is that due to adverse environmental conditions, such as heat, drought and frost, a high rate of mortality of germinants and small seedlings is predicted. "Indeed, mortality at the seedling stage may effectively preclude any tree establishment where environmental conditions are severe" (Franklin et al. 1992). It is these 'surprises' associated with climate change that may threaten the re-establishment of forests as they attempt to extend northward. Thus there could be substantial negative impacts on the Boreal Forest of Canada as well as an enhancement of the global greenhouse effect if die-offs and burning increase while re-establishment declines.

For a doubled greenhouse gas scenario, Thompson *et al.* (this Workshop) have described the changes that might ensue specifically in Ontario forests, while Hebda (also this Workshop) has assessed the changes that might occur in British Columbia using paleoclimate analogies.

Prairie Ecosystems: The Canadian prairies are expected to become both warmer and drier, which could have an adverse impact on biodiversity. The agricultural industry and urbanization have already greatly affected the biodiversity of the prairies as more than 80% of the native prairie landscape and approximately 75% of the aspen parkland (a mixture of wooded areas, water and grasslands) have been transformed as well as 70% of wetland habitat (Government of Canada, 1991). The prairie wetlands of the upper US Midwest and southern Canada are the single most important breeding area for waterfowl in North America (Gates, 1993). As the climate in this region becomes warmer and drier, many of the remaining waterfowl staging areas may vanish or become smaller and shallower. The consequence is that "waterfowl may respond by migrating to different geographical areas, relying more heavily on semi-permanent wetlands but not breeding, or failing to re-nest as they currently do during periods of drought" (Poiani & Johnson, 1991). These wetlands produce 50-80% of North America's total duck population (Batt et al., 1989).

The prairie grasslands may also become threatened as it is uncertain whether they will be able to survive in the drier conditions. Also these conditions may cause a decline in agricultural productivity. During the 1988 drought, grain productivity decreased between 20-30% (Woodwell, 1992). This is an example of a direct climatic impact on an economic resource which also has significance for the biodiversity of the area as irrigation, new crop strains and other technologies may influence the biodiversity of the area. A new threat to grasslands was discussed by both Wedin and Hutchinson at this Workshop, viz., the impacts of human alteration of the global nitrogen cycle. Chronic nitrogen loading results in large biodiversity losses, and thus poses a threat to ecosystem functioning.

Arctic Marine Ecosystems: Canada is adjacent to oceans on three sides. All three are unique but a discussion of the Arctic marine ecosystem will serve as an example of some of the impacts of climate change. It is expected that as climate changes, many southern species will take over arctic areas. The Canadian Arctic is expected to persist longer than other arctic ecozones such as in Alaska, and therefore be a refuge for many arctic species (Alexander, 1992).

The impacts expected within the ocean environment as outlined by Alexander (1992), are:

1) *decrease in sea ice cover, leading ultimately to an ice-free Arctic Ocean*

- this will eliminate thermohaline convection, presently believed to be an important mixing process, the upwelling bringing nutrients to the surface;
- this will reduce the nutrient input to coastal regions and result in lower primary production;
- the nutrient input will also be reduced because of the loss of the undersurface of sea ice, which is a major site for algae and marine invertebrates (Hansell, this Workshop).

2) *sea level rise*

- this will affect fresh water levels, as well as coastal flooding and erosion (Note that the wetlands on the southern part of Hudson's Bay are still rebounding from the last Ice Age).

3) *an increase in coastal erosion in arctic tundra from permafrost melting*

The Arctic coastline is a primary breeding ground for many migratory birds such as plovers, sandpipers and terns. There are 49 species of shorebirds that breed in the Canadian Arctic (Government of Canada, 1991). As Arctic coastal zones change due to permafrost melting and sea level rise, many breeding sites will be lost. As climate changes, the timing of migration may be affected and habitat as well as food supplies may not be suitable.

Species especially vulnerable are seals, walrus and polar bears, which require an ice platform to survive. Other species such as the polar cod may be lost because of a reduction and possible elimination of ice algae and other ice associated communities. Alexander (1992) believes that "essentially all the distinctive arctic animals would disappear" due to atmospheric change.

Great Lakes Ecosystems: This region is the most commercially developed in Canada. Almost half of Canada's endangered and threatened wildlife species (46) inhabit the Great Lakes-St. Lawrence basin (Government of Canada, 1991). Many of these species are associated with the extension into southwestern Ontario of the Carolinean deciduous forest ecosystem, a floral and fauna complex that is more typical of the southeastern and central United States (Government of Canada, 1991).

Wetlands are the most productive and diverse components of the Great Lakes-St. Lawrence ecosystem. However, approximately 80% of southern Ontario's original 2.38 million hectare of wetlands have been lost mainly due to conversion into agricultural land and urbanization (Koshida et al., 1993). The aquatic environment of the Great Lakes-St. Lawrence ecosystem has been badly degraded by industrial development and pollution. Decreases in water supply due to climate change could cause major alterations and losses in wetland and aquatic ecosystems.

Non-native species now comprise a significant proportion of the biological diversity within the Great Lakes ecosystem (Government of Canada, 1991).

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Chapter 2: Atmospheric Change and Biological Diversity: Possible Role of UNEP in Developing the Linkages[5]

2.1. Introduction

The year 1992 stands out as a most significant one in the history of the environmental movement: first because it was 20 years after the Stockholm Conference and therefore an appropriate time to take stock of the advancement since Stockholm; second because it was the year when it became clear that environmental conservation and economic development need not work at cross-purposes and that indeed one can have what is now popularly known as "Sustainable Development"; thirdly, because this was the year when two particularly important Conventions were agreed at an all important United Nations Conference on Environment and Development (UNCED) - the United Nations Framework Convention on Climate Change, and the Convention on Biological Diversity.

Prior to these treaties coming into force, another international treaty - the Vienna Convention for the Protection of the Ozone Layer - had been agreed to forestall possible damage to human health and the environment through the modification of the ozone layer by chlorofluorocarbons.

In Article 2 of the United Nations Framework Convention on Climate Change it is clearly articulated that its "ultimate objective is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." "Such a level", it adds "should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change..."[6] The convention on Biological Diversity has as its primary objective "the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of its benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies..."[7]

Seeking to achieve the objective of the Convention on Biological Diversity assumes that people will not, through actions that would adversely change the composition of the atmosphere, affect biological diversity because one can only conserve and exploit - albeit sustainably - what exists.

The purpose of this paper is to trace UNEP's role in the development of these conventions as a basis for a discussion on how best we may move foreword in defining the linkages between atmospheric change and biological diversity. I note the significance of the word "atmospheric" as opposed to "climate" change because this gives us the opportunity to address issues such as atmospheric pollution and ozone layer modification as they affect biological diversity. We shall trace the history of the atmospheric change debate up to the signing of the Vienna Convention and the Climate Convention; then we shall trace the history of biological diversity issues in UNEP up to the Convention on Biological Diversity. We believe that UNEP's role in these processes places it at a vantage point to contribute significantly to the debate on emerging issues in the two areas and in developing an appropriate course of action for the future. Drawing on past biological diversity will be flagged and finally a discussion will be given on how these linkages suggest the direction in which the debate concerning future action should be steered.

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[5] *Paper presented by A. Alusa at Workshop*

[6] UN Framework Convention on Climate Change.

[7] Convention on Biological Diversity: UNEP Environmental Law and Institution Project Activity Centre, Nairobi-Kenya, 1992.

2.2. Atmospheric Change

2.2.1. Introduction

UNEP's involvement in atmospheric change issues dates back to the Stockholm Conference and the mandate it received. The protection of the environment obviously includes the protection of the atmospheric environment. No attempt will be made here to list the various pioneering efforts by UNEP in this field, but two of these efforts seem particularly noteworthy in the context of this workshop, namely protection of the ozone layer and climate change or global warming.

2.2.2. Protection of the ozone layer

One of the issues that has engaged the scientific community in the recent past is the question of the depletion of the ozone layer. For over 15 years accumulated evidence has suggested that the ozone layer is being seriously depleted over Antarctica and that that would have serious repercussions to the welfare of humans, animals and ecosystems. As these concerns mounted during the mid-seventies, UNEP was asked to coordinate a World Plan of Action on the ozone layer. A Coordinating Committee on the Ozone Layer (CCOL) consisting of representatives of Governments, organizations and chemical manufacturers was established to assist in the task. Several studies and assessments were carried out starting in 1977 and these formed the basis for the Convention for the Protection of the Ozone Layer adopted in Vienna in 1985. After two more years of intensive negotiations, efforts to protect the ozone layer took a vital step forward with the adoption of the Protocol on Substances that Deplete the Ozone Layer in Montreal in September 1987.

The Vienna Convention entered into force on 22 September 1988 and the Montreal Protocol on 1 January 1989. The first Meeting of the Conference of the Parties to the Vienna Convention and the First Meeting of the Parties to the Montreal Protocol were held in Helsinki from 26 to 28 April 1989 and 2 to 5 May 1989, respectively. The Parties decided, *inter alia,* to designate UNEP as the Secretariat for the Vienna Convention and its Montreal Protocol. During these Meetings, the 81 Governments present adopted the Helsinki Declaration on the Protection of the Ozone Layer which expressed the political commitment to go further than the requirements of the Montreal Protocol.

The Second Meeting of the Parties to the Montreal Protocol was held in London from 27 to 29 June 1990. At this Meeting, the Parties adopted the adjustments and the Amendment to the Montreal Protocol. The adjustment strengthens the control measures (Article 2), requiring the Parties to phase out the production and the consumption of the five CFCs and the three halons listed in Annex A of the Protocol by the year 2000. The adjustments which are binding to all Parties to the Protocol, entered into force on 7 March 1991.

The London Amendment to the Montreal Protocol includes the control of ten other CFCs, carbon tetrachloride and methyl chloroform. The production and consumption of these substances are required to be phased out by the year 2000 except for methyl chloroform which should be phased out by the year 2005. The Amendment also includes a strengthened provision on the transfer of technology and a financial mechanism that will facilitate the necessary transfer of technology and enable developing countries to comply with the Protocol. The London Amendment entered into force on 10 August 1992.

The Fourth Meeting of the Parties to the Montreal Protocol was held in Copenhagen in November 1992, when the Parties adopted further adjustments and an Amendment to the Montreal Protocol. The adjustments require the phase-out of five CFCs in Annex A of the

Protocol by 1996 and the three halons by the year 1994. All Parties to the Montreal Protocol must comply with these further strengthened control measures.

The Copenhagen Amendment requires additional substances, HBFCs to be phased out by the year 1996 and HCFCs by the year 2030. The consumption of methyl bromide should be frozen at 1991 levels by the year 1995 and meanwhile further studies will be carried out on the impact of methyl bromide on the ozone layer and the economic implications of the phase-out. Also in 1995, the Parties were to conduct a review of the implementation of the provision on technology transfer and the financial mechanism and decide how these control measures should apply for developing countries. The Copenhagen Amendment entered into force on 14 June 1994.

As of 30 June 1994, 136 States and the EEC were Parties to the Vienna Convention and 135 States and the EEC were Parties to the Montreal Protocol. The London Amendment has been ratified by 27 States.

We shall discuss the significance of these treaties for biological diversity later. Suffice to state here that the depletion of the ozone layer and subsequent increase in UV-B radiation incident on the earth's surface has serious ramifications for biological diversity. The programme of international scientific assessment and the subsequent environmental management of the issue demonstrates, as perhaps no other project has, the effectiveness of the UNEP programme in addressing environmental concerns. That the risks to the ozone layer were initially theoretical rather than proven, underscores UNEP's importance in coordinating and effecting rapid response to environmental emergencies.

2.3. Climate Change Issues

The possibility of global climate change as a result of increasing concentrations of CO_2 and other greenhouse gases is a matter of considerable concern to policy makers and the international scientific community. UNEP's programme has been one of assessment as a prelude to environmental management. The first international assessment was not held until 1980. The assessment meeting was convened under a decision of the 7th session of the Governing Council of UNEP and was undertaken by an expert group in Villach, Austria. This was the first of a series of four major greenhouse-gas-related meetings held in Villach. The most important was the one undertaken in 1985 under the joint auspices of ICSU/UNEP/WMO (1986). Considerable preparatory work had gone into this meeting including the commissioning by UNEP and WMO of a major research programme on the impact of climate change on ecosystems by the International Meteorological Institute (IMI) in Stockholm. The Villach assessment confirmed the risk and was instrumental in galvanizing international action, to improve scientific knowledge and develop appropriate responses. It was published in cooperation with ICSU/SCOPE by the IMI under the title "The Greenhouse Effect, Climatic Change and Ecosystems" (SCOPE 29, 1986).

Assessments after 1985 became the responsibility of the UNEP/WMO Intergovernmental Panel on Climate Change (IPCC). The IPCC First Assessment report on the specification of climate change, of the impacts of such changes, and of possible response options was completed in 1990. This report, although acknowledging the many scientific uncertainties on the behaviour of the climate system and on the implications of its change due to anthropogenic influence, confirmed the earlier scientific concerns that the increasing concentration of greenhouse gases in the atmosphere would lead to global warming and that sea-level would rise as oceans warm and expand.

The Ministerial Component of the Second World Climate Conference which examined the IPCC First Assessment Report recommended that negotiations start as soon as possible on a Framework Convention on Climate Change. The General Assembly decided during its 45th Session to start negotiations under United Nations auspices and in 1990 established an Intergovernmental Negotiating Committee. In May 1992, the Negotiating Committee agreed a draft Framework Convention on Climate which was signed during UNCED 1992 in Rio de Janeiro.

2.4. Biological Diversity

The Governing Council of UNEP in its decisions 14/26 and 15/34 formally recognized and re-emphasized the need for concerted international action to protect biological diversity on Earth by, *inter alia*, the implementation of existing legal instruments and agreements in a co-ordinated and effective way and the adoption of a further appropriate international legal instrument, possibly in the form of a framework convention.

The first session of the *Ad Hoc* Working Group of Experts on Biological Diversity, established pursuant to Governing Council decision 14/26, was held in Geneva in November 1988.

The second session of the Working Group was convened in Geneva from 19 to 23 February 1990 to advise further on the contents of a new international legal instrument, with particular emphasis on its socio-economic context. At that session, the Working Group made significant progress on a number of outstanding issues related to the preparation of a new legal instrument. The Group recommended the preparation of a number of studies as a means of responding to specific issues in the process of developing the new instrument.

To assist in the preparation of more accurate estimates of the total costs of global biological diversity conservation needs, the Secretariat contacted nine developing and developed countries (Brazil, Federal Republic of Germany, Indonesia, Madagascar, Nepal, Peru, Poland, Uganda, Zaire) with regard to initiating country studies to determine approximate conservation sites and conservation needs that have not been met.

The Ecosystems Conservation Group (ECG) [FAO, UNESCO, IUCN and UNEP] was active as it considered the substance of UNEP Governing Council decisions at its fifteenth general meeting held in Gland in September 1988 and reviewed the matter of draft elements for consideration in the new legal instrument on biological diversity at a Special Session in Rome in April 1990.

The third session of the *Ad Hoc* Working Group of Experts on Biological Diversity was held in Geneva in July 1990 to advise further, *inter alia*, on the contents of elements for a global framework legal instrument on biological diversity in accordance with decision 15/34 of UNEP's Governing Council.

Throughout these discussions key and contentious issues related to the need to conserve biodiversity and the right of States to exploit their resources. There was further debate on whether the convention should be limited to wild species or should include domesticated ones. It was agreed that the convention would include both and that whereas it was desirous to conserve biological diversity, States had a sovereign right to exploit resources within areas of their jurisdiction. Other sensitive issues related to access to genetic resources and transfer of technology. The final treaty agreed in 1992 provides for all these concerns in its objectives and other relevant articles. The scientific assessment that supported these activities has been published (UNEP, 1995).

2.5. What are the Linkages between Biodiversity and Atmospheric Change?

In discussing the history of the various treaties related to atmospheric change and biological diversity, effort was directed towards showing that UNEP has provided the necessary leadership in ensuring the efficient management and use of environment resources. These treaties may appear unrelated but have considerable areas of commonality.

Both the Vienna Convention and the Climate Convention are "Framework" conventions. This means that the general treaty resolves in principle to tackle the problem with a view to following up with the more difficult task of agreeing on protocols or other legal controls to achieve the overall objective of the convention.

The main thrust of the Vienna Convention is an agreement on cooperation with regard to scientific research and observation to improve the understanding of the atmospheric processes, as well as on formulation of legislative and administrative measures to reduce and eliminate the use of substances that might deplete the ozone layer. It also requires cooperation on exchange of information on technical, socio-economic, commercial and legal aspects of the protection of the ozone layer.

The Biological Diversity Treaty has articles that cover observation and monitoring of biological diversity (Article 7) and research and training in biological diversity. The Climate Convention has a provision for research and systematic observation (Article 5) and an advisory body on Scientific and Technical Advice (Article 9) which would provide assessments of the state of scientific knowledge relating to climate change, its effects and possible measures to respond to these.

What, then, are the linkages between atmospheric change and biological diversity?

2.5.1. Ozone Layer Depletion and Biological Diversity

The Scientific Committee on Problems of the Environment (SCOPE) has issued a report partly supported by UNEP on the Effects of Increased Ultra Violet Radiation on Global Ecosystems (SCOPE 1993). The studies show that while there are many unknowns, there is suggestive evidence that:

a) increased UV-B is harmful to many aquatic organisms;
b) increased UV-B can reduce flowering activity of plants and therefore productivity;
c) increased UV-B affects plant chemical composition.

The key unknown are:

a) too little is known about many ecosystems and how they function;
b) because of the above, the effects of UV-B on such systems is difficult to determine.

The important point to raise here is that the depletion of the ozone layer would increase UV-B radiation incident on the surface of the earth and this in turn would affect plant, animal, and human health and may adversely modify biological diversity.

2.5.2. Climate Change and Biological Diversity

The IPCC in its Second Assessment Report is quite unequivocal that "the balance of evidence supports a discernible human influence on global climate", and that "climate is expected change in the future" (IPCC, 1995). Since most systems are sensitive to climate change, and certainly human-induced climate change is an important additional stress, it is expected that ecosystems will be affected and depending on how fast climate changes, it is most likely that biodiversity will be adversely affected. The IPCC points out that the shifts in the distribution of forest zones take place with significant time lags, but it is expected that climatic changes in future will take place over a much shorter time horizon. It is this rate of change of temperature and therefore the rate of movement of ecosystems or forests that will take a toll on biological diversity.

Biodiversity can be affected directly by climate change or indirectly through changes in ecosystems and habitat destruction. As it is, biological diversity is under stress through ecosystem destruction by land use changes and over-exploitation of forests through wanton deforestation. Climate change can only make things worse. It is expected that there will be significant loss of species due to climate change and because climate change would be permanent, this impact is considered by the IPCC as the most significant of all the impacts of climate change.

Climate change will lead to sea level rise. During the negotiations for the climate convention, the Small Island States were particularly concerned by their vulnerability to sea level rise. This concern is not misplaced especially with regard to the impact on their biological diversity. Island biological diversity is known to include endemic species with unique gene traits. When sea level rises, the chances of these species becoming extinct are very high.

2.6. UNEP's Role in Future Development of Linkages

We have outlined how UNEP was catalytic in the advancement of the debates on ozone layer depletion, climate change and biological diversity. We have seen that a common denominator of all these developments is the foresight to identify emerging issues, galvanize scientific inquiry and raise political awareness leading to global action in the form of treaties. Additionally, we have seen that most treaties have provision for continuing observations, monitoring and research in order to ensure that the Conferences of the Parties are fully apprised of new scientific findings that may necessitate action on their part in order to respond to any new knowledge and/or emerging issues.

One glaring problem is that we have three or more treaties which call for making observations, monitoring events, and carrying out research. We believe that there is considerable interdependence of issues, events and actions. For example, in addressing the need to eliminate CFCs, the Montreal Protocol also addressed the problem of Climate Change because CFCs have a high global warming potential.

The IPCC in looking at the impacts of expected climate change needs to have a forum for linking with the Scientific and Technical bodies set up under the Biodiversity Convention for observation and monitoring of biological diversity. An assessment of impacts must be based on an informed understanding of the nature of biological diversity and ecosystems and habitats in which it occurs.

As pointed out earlier, when UNEP began to respond to the call for action in 1977 regarding the ozone hole, the Coordinating Committee on the Ozone Layer was established to carry out studies and assessments on the depletion of the ozone layer. Under the Montreal Protocol a provision was included to continue the assessments periodically and to revise the control measures on the basis of the latest information obtained through the assessments. The Climate Convention and the Biological Diversity Convention provide for similar assessments which we propose should have a mechanism for relating to each other. The Global Biodiversity Assessments, IPCC Assessments, the Ozone Layer Depletion Assessments and other assessments should constitute a continuing inquiry into the various problems and be a basis for further action under the treaties.

We have developed a UNEP Biodiversity Programme and Implementation Strategy, which is a framework for supporting global conservation and sustainable use of biodiversity. Similarly, drawing on the work of the IPCC Working Group II and the work of the Intergovernmental Panel on Forests, UNEP is developing a strategic policy on playing a lead role in the debate on the linkages between the various aspects of atmospheric change and biological diversity. Whereas this is only now evolving, it will include a role in galvanizing strategic research through organizations like SCOPE to address the scientific uncertainties that presently plague our understanding of:

a) impacts of UV-B on ecosystems, forests and biological diversity;
b) the biosphere feedback on climate change;
c) impacts of climate change and sea level rise on ecosystems, forests and biological diversity.

It will also include the need to evolve an integrated approach in addressing the global change issue both at the scientific and political levels.

2.7. Conclusion

We have described the role that UNEP has played in the two atmospheric change debates and the biological diversity debate and we have delineated how these demonstrate UNEP's leading roles in environmental protection and management. We have pointed out that there exist clear and identifiable linkages between atmospheric change and biological diversity through examples drawn from the ozone layer depletion, climate change, and biological diversity issues as cases in point. Given UNEP's track record, we suggest that there is a niche for UNEP in advancing the global change debate in as far as environmental protection and management are central to this debate.

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Chapter 3: OVERVIEW OF THE WORKSHOP[8]

3.1. Summary of Presentations in the Plenary Sessions

The first day of the Workshop featured five plenary presentations. In his welcoming address, **R. Slater**, Assistant Deputy Minister of Environment Canada's Environmental Conservation Service, challenged workshop participants to develop recommendations for cost-effective policy measures to conserve biodiversity, and to develop effective communication tools to educate the Canadian public and decision makers about the linkages between atmospheric change and biodiversity. Mr. Slater also emphasized the need for the development of early warning indicators for climate change and biodiversity change.

In his keynote lecture, **J. McNeely** (Chief Scientist, IUCN) explained that the Earth's climate has always been changing, but current and projected changes are unique in that they are superimposed upon a landscape which has already been greatly altered by human activity. The rate at which human activities are altering the natural environment, the extent of that alteration, and the consequences for biodiversity and degradation of ecosystem functions are likely to be unprecedented. These global pressures on the environment are due to a combination of factors including increasing population, increasing *per capita* consumption, depletion of natural resources systems, and inappropriate management institutions. These pressures are expected to continue to grow, and to be exacerbated by climate change and other atmospheric stresses.

The various atmospheric stresses of current concern in Canada and elsewhere were elaborated by **D. MacIver**. These stresses (see Section 1.3) could act singly or synergistically to cause damage to biodiversity and ecosystem functions. Biodiversity cannot be protected, utilized or fairly shared without an assessment of the effects of, and adaptation to this host of atmospheric stresses. Scientific assessments based on single species and single stresses must expand towards a more holistic science and policy, considering multi-atmospheric stresses in an ecosystem framework.

D. Wedin used examples from grassland ecology to illustrate the linkages between biodiversity and ecosystem functioning. Although it has been suggested that "each species has a unique role in its ecosystem", this paradigm is not well supported by actual ecological research. Species represent the range of physiological and chemical traits available to an ecosystem. The productivity, sustainability and stability of an ecosystem may be influenced by its biodiversity (Tilman et al., 1996). However, controlled experiments suggest a saturating dependence on plant species diversity, and species redundancy may occur at high diversity. Wedin used Nitrogen (N) deposition as an example to show the threat to biodiversity and to ecosystem functioning posed by increased rates of atmospheric pollution. Experiments show that high-diversity, native prairie grasslands have large biodiversity losses in response to chronic N loading.

The role of the United Nations Environment Programme (UNEP) in developing the linkages between atmospheric change and biodiversity was addressed by **A. Alusa** (see Chapter 2).

The **second day** of the workshop featured four plenary presentations. **T. Hutchinson** examined the impacts of acidic deposition on floral changes in Europe and North America. Although the impacts of acidic deposition have been observed and described for the past 100 years, the major concerns have arisen since the early 1970s as a result of widespread regional acidification. The impacts were initially noted on local flora. Many lichen species were eliminated from urban areas, and many tree species were found to be unable to survive the polluted city environments in

[8] *Contributed by A. Maarouf and L. Cartmale*

western Europe and eastern North America. The regional effects of emissions of sulphur and nitrogen oxides have been increasingly documented in both aquatic and terrestrial systems. Detailed long-term records of plant communities and their changes exist, e.g. in Sweden, Germany, UK and the Netherlands. While many species appear to be in decline, some acid tolerant grasses and sedges have shown increases. In Canada, long-term records do not exist; however, the Sudbury area should provide a model system for studying atmospheric and environmental changes.

D. Welch viewed atmospheric change and ecosystem protection from a national parks perspective, illustrating with several case histories. These included acidification studies at Kejimkujik, studies of campfire smoke in Jasper, La Mauricie and Forillon, and automobile emissions from through traffic in Yoho. Several atmospheric and environmental issues were found to affect the maintenance of ecological integrity in Canada's national parks, including forest fires, acidification, pesticides, eutrophication from airborne nitrates, permafrost melting, and UV-B. Of 28 environmental stresses recognized as significant for national parks in 1992, acidic deposition ranked 8th, pesticides 18th, heavy metals 21st, and climate change 23rd. In 1995, an International Air Issues Workshop recommended that the monitoring needed most by national parks is of suspended particulates and visibility. The atmospheric research most needed is the modelling of natural landscapes and vegetation complexes in response to climate change.

I. Thompson gave an overview of the effects of global climate change on landscape diversity, using Ontario forests as an example. Climate warming will have profound impacts on forest ecosystems and landscapes in Canada. For a doubling of CO_2, the fire weather index (FWI) is predicted to rise over much of Ontario 1.5 to 2 times its present value and by as much as 5 times in central-south Ontario. Warming and greater than average fire occurrence will result in a shrinkage of area covered by the boreal forest towards the north and east. Pyrophilic species will become most common, especially jack pine and aspen. Patch sizes will initially decrease then expand resulting in considerable homogenization of forest landscapes. There will be little 'old-growth' forest and landscape disequilibrium will be enhanced. Some species, particularly those with heavy seeds, may not be able to adapt to rapid changes in climate, and local extinctions are to be expected. Wildlife species that respond at the landscape level, i.e., those with body size > 1 kg, will be most affected by changes in landscape structure. In particular, moose and caribou populations are expected to decline significantly, while white-tailed deer will likely become abundant across Ontario and Quebec.

P. Timmerman outlined the social and economic implications of atmospheric and biodiversity change. These changes must be seen in a global context of major shifts in the conceptualization and management of human relationship with nature. If the impending physical changes are not placed within the context of these shifts, the range of possible responses will be unduly narrowed. Traditionally, the biosphere has been conceptualized as separate from human beings. However, ecosystems are becoming subject to more and more human management. This raises not only economic issues, but also social, political and ethical concerns that will have substantial influence on public policy. Among these are the commodification of genetic material, the privatization of traditional knowledge, and the management of information. Current and proposed strategies of response to atmospheric changes must be evaluated in terms of their appropriateness to biodiversity changes. A sensible strategy would have to relate multi-issue atmospheric stresses to multi-sectoral impacts and responses. Ways are needed to demonstrate the linkages between the array of issues, and in particular the linkages between human behaviour and global environmental change.

The **third day** of the workshop began with six short presentations which highlighted a number of sectoral and regional concerns. **R. Hebda** explained that paleoecological analogues reveal that major changes must be expected as a result of climate change in forest composition, range, structure and ecological processes. In British Columbia, warmer and drier climates in the distant past supported a different forest pattern, including forest types with no modern analogue, dramatically different disturbance regimes, specifically more fires, and different tree growth rates. Wetlands and grasslands were different, suggesting implications for wildlife biodiversity. B.C.'s Forest Practices Code prescribes guidelines for biodiversity objectives, but ignores the issue of atmospheric change. This apparent omission may result from lack of understanding of the profound potential effects of atmospheric change on forest biodiversity and a lack of mechanisms to assess impacts on regional and local scales to develop management strategies.

R. Elliot drew examples of atmospheric change and biodiversity from Atlantic Canada's wildlife. Environment Canada's interpretation of "wildlife" has broadened with the growing emphasis on an ecosystem approach, to include most components of biological diversity. Although some atmospheric changes will affect wildlife directly, most act indirectly through changes and destruction of habitats. Chemical substances such as sulphates, heavy metals, and organochlorines affect higher trophic levels of food chains, such as eagles, ospreys, loons, marine mammals, and other top predators. Levels of organochlorines and metals in seabird eggs from Atlantic Canada document changes affecting these birds from atmospheric and other sources. Long-range transport of airborne pollutants have direct, indirect, and cumulative impacts on wildlife in conjunction with other stressors. Combined effects of reduced pH and highly organic waters in southwestern Nova Scotia may enhance uptake of mercury by fish and loons. Impacts of increasing levels of atmospheric CO_2 and UV-B radiation on wildlife diversity may be indirect through changes in food species, but are harder to assess in Atlantic Canada. However, sea-level rise will certainly affect wildlife populations as coastal habitats are inundated. Studies of wildlife are therefore important as indicators of species status, atmospheric and environmental changes as well as of ecosystem integrity.

E. Wheaton emphasized that biodiversity and agroecosystems in the Canadian prairies are being threatened by human activities and atmospheric stressors. The dominance and importance of agriculture in the region, and the marginal nature of its climate cause major concerns for biodiversity under the predicted weather, climate and other atmospheric changes expected (e.g. droughts, floods, soil erosion, long-range transport of air pollutants, etc.). Synergistic effects of environmental and atmospheric changes are likely to have some positive and many negative impacts on crops and natural vegetation in the prairies.

B. Freedman stated that the most important threats to biodiversity are currently associated with extensive conversions of natural ecosystems into anthropogenic ones that are largely managed in the interest of human needs and wants. Most important in this regard are conversions of old-growth forests in the tropics and temperate zones into agriculture or industrial habitats that sustain few of the original, often locally endemic species. Other losses of biodiversity have been associated with commercial over-exploitation of biological resources, as evidenced by extinctions of the great auk, Labrador duck, passenger pigeon, Carolina parakeet, and blue pike, and the endangerment of many other species. With reference to aquatic biodiversity, Freedman noted that some of the atmospheric stresses have well documented effects, e.g. acidic deposition and trace deposition of persistent chemicals that bio-accumulate in food-webs. The influences of other stresses such as increased UV-B radiation and climate warming on aquatic biodiversity are less-well described and understood.

R. Hansell explained that the Canadian Arctic is characterized by a high variation in landform and a complex interaction with climate which is revealed in the distribution of biota. Accurate predictions of climate change are needed to assess the potential change in treeline, which could lead to a 90% loss of the Quebec tundra ecosystem. Sea ice in Hudson's Bay and other coastal areas is a major factor in marine-terrestrial ecosystem interactions. Climate warming and UV-B increases will affect several Arctic species including polar bear, seals, Arctic fox, as well as many plant species, thus causing serious disturbance to Arctic ecosystems. Rise in sea level will flood many marine salt marsh communities leading to changes in distribution of plants and colonizers such as snow geese. Warming will have major effects on permafrost and ground-ice causing destabilization of slopes and disruption of the tundra. Improved navigation in the Arctic will increase human impacts with subsequent introduction of weedy species and disruption of local plant communities.

Finally, the linkages between atmospheric change, biodiversity and human health were addressed by **R.E. Munn**. Climate-induced ecological changes could force the rapid evolution of infectious agents, with newly emergent strains of altered virulence or pathogeneity. Predator/prey ratios could be disrupted, loosening natural controls on pests and pathogens. Explosive increases in the populations of some pests including invasive species might occur, leading to alterations in biodiversity regimes, thus affecting food and fiber production and the availability of medicinal plants. Changes in the biodiversity of lakes may lead to diminished water quality and fisheries yields. Warming of coastal waters may cause increased frequencies of amnesiac, diarrheic and paralytic shellfish poisoning of humans as well as sea mammals, seabirds and fin fish. The effects on human health as a result of changes in biodiversity are complicated by: (1) other atmospheric and environmental stressors such as increased heat-waves, air pollution episodes, and declines in water and food quality; and (2) confounding factors such as the aging Canadian population that may become more susceptible to environmental stresses in the 21st century.

3.2. Introduction to the Working Group Sessions

The Workshop participants were assigned to five Working Groups (WGs) that included roughly equal numbers of atmospheric scientists and biodiversity specialists, plus a few generalists. In most cases, this involved appointing the Chair and the Rapporteur from different disciplines. The five WGs were: I) Ecosystem Functioning, II) Landscape Ecology, III) Biomes and Sectors Most at Risk, IV) Socioeconomic Consequences and Policy Implications, and V) Self-Organizing Ecosystems. Arising from the general discussions in the plenaries, all five WGs were challenged by R. Slater and I. Burton to consider three additional questions: (a) Will biodiversity change give an integrated picture of atmospheric change and thus provide an early warning of atmospheric change? (b) Conversely, will atmospheric change provide an early warning of biodiversity change? (c) Are the linkages between atmospheric change and biodiversity change sufficiently strong that policies can be established to slow down or mitigate harmful biodiversity trends?

Perhaps one of the most significant outcomes of the WG sessions was the emphasis on considering "big picture" implications as well as more detailed ones. The groups all referred to the paper presented by P. Timmerman on the importance of social and economic implications of changes in biodiversity and several WGs included social and economic considerations in their focus, underlining the importance of such questions alongside hard scientific evidence. Following presentations from the WG rapporteurs (Chapter 4), the final day of the Workshop was devoted to a panel and general discussion focusing on "Where Do We Go From Here?" (Chapter 5).

REFERENCE

Tilman, D., Wedin, D., and Knops, J. (1996) Productivity and sustainability influenced by biodiversity in grassland ecosystems, *Nature, 379,* 718-720.

Chapter 4: WORKING GROUP REPORTS

4.1. REPORT OF WORKING GROUP I: Implications of Atmospheric Change for Biodiversity and Ecosystem Functions[9]

Chair: Don MacIver **Rapporteur**: Bill Freedman **Participants**: Allan Baker, Steve Beauchamp, Wade Bowers, Ian Hogg, Gray Merriam, Jacques Prescott, Richard Raddatz, Jeff Watson, Doyle Wells, Bruce Wiersma.

4.1.1. Ecosystem Functions

Ecosystem functions can be defined as: "the transport and transformation of energy and matter in ecosystems." Examples of ecosystem functions include productivity, decomposition, nutrient cycling, nitrogen fixation, hydrology, trophic interactions (e.g., herbivory, carnivory, parasitism), succession and regression, and evolutionary responses to environmental changes and heterogeneities.

Ecosystem functions provide services that are critical to the support of humans and their livelihoods. Economically important ecosystem functions include the productivity of diverse renewable natural resources, such as commercial forests, fish stocks, agricultural crops, and soil capability. Other ecosystem services are not conventionally valuated in the marketplace, but are nevertheless important to the welfare of humans and other species. Examples of these ecological services are shown in the box.

Some Important Ecosystem Services that are Difficult to Evaluate in the Marketplace

- Maintaining the hydrological cycle
- Regulating climate
- Maintaining the gaseous composition of the atmosphere
- Generating soils
- Cleansing air, water and soil
- Pollinating agricultural crops
- Storing and cycling nutrients
- Providing tourist and recreational services

Some important generic considerations relevant to ecosystem functions include the following:

(1) **Many Functions have a Degree of Robustness to Changes in Biodiversity**. Most ecosystem functions are carried out by diverse assemblages of species, a fact that confers an element of robustness to the effects of changes in species composition (this is sometimes referred to as "resistance" in the ecological literature). For example, in most ecosystems, productivity and decomposition are accomplished by the integrated actions of many species of micro-organisms, plants, and animals. Within limits, these functions continue to be accomplished even if some of these species are removed from the system, or are replaced by other species.

Robustness is not, however, the case for all ecological functions. For example, the process of nitrification, i.e., the oxidation of ammonium to nitrate in non-acidic soil and water, is only carried out by two genera of bacteria, which operate in a step-wise fashion. *Nitrosomonas* is responsible for the oxidation of ammonium to nitrite, and *Nitrobacter* then oxidizes the nitrite to nitrate, a

[9] *Contributed by B. Freedman*

critically important nutrient for plants and many micro-organisms. There is no redundancy of biodiversity in this particular ecological function -- elimination of either *Nitrosomonas* or *Nitrobacter*, for example by habitat acidification, will cause immediate failure of this important function of chemical transformation. Even for those ecological functions for which there is a substantial degree of robustness in terms of changes in species composition, there are limits to this flexibility. If too many species are eliminated, there may be a substantial degradation of the ability of the ecosystem to provide the functional service. Degradations of ecological function often develop rapidly after a threshold of resistance has been exceeded. This factor may be useful in the determination of criteria for protection of ecological functions, and in the design of useful indicators of the integrity of functions.

(2) **Species Vary in Their Provision of Ecosystem Services**. Through their various activities, all elements of biodiversity are involved in ecosystem functions, and therefore provide ecosystem services. It is important, however, to recognize that elements of biodiversity can vary enormously in their relative importance in this regard. For example, so-called "dominant" species contribute disproportionately to the biomass of their ecosystem (as would be the case of the most abundant species of tree in a forest). Obviously, dominant species contribute a relatively large fraction of the productivity and some other functions of their ecosystem. Therefore, targeted damage to dominant species will cause large degradations of those ecosystem functions in which they are prominent. Because of their importance, dominant species are useful as indicators of the integrity of their ecosystem.

Some other species, known as "keystone" or "regulator" species, have a prominence in ecosystem functions that is much greater than would be expected on the basis of their relative biomass within the ecosystem. For example, because of their critical role in nitrogen cycling, *Nitrosomonas* and *Nitrobacter* are regulator species in most non-acidic ecosystems. Spruce budworm is a regulator in mature forests of balsam fir, because it causes stand-replacement disturbances through their intensive herbivory on foliage of fir trees, the dominant species in that ecosystem. Because of their disproportionate importance in the provision of certain functions, regulator species are highly valued components of biodiversity, and are potentially useful indicators of ecosystem integrity.

The character of dominant and regulator species can change over time, as ecosystems are affected by environmental stressors, such as climate change, disturbance, or invasion by alien species. Under such conditions, initially dominant species may disappear, while new dominants emerge, and similar changes can occur to regulator species. These ecological changes may be relatively persistent, leading to the development of a so-called "alternate stable state." For example, overgrazing associated with increased populations of snow goose in certain places along western Hudson Bay has converted salt marshes dominated by lawns of the grass *Puccinellia phryganodes* into much more sparsely vegetated mudflats. In another example, chestnut trees were once co-dominant species in many mixed-species angiosperm forests in eastern North America, but this species was selectively eliminated by the ravages of an introduced fungal pathogen. This provided an ecological opportunity for other species of trees, which expanded their own degree of dominance in the forest, greatly changing the character of the ecosystem.

(3) **Scale is an Important Context for Ecological Services**. Rates and heterogeneity of most ecosystem functions are highly sensitive to spatial and temporal scales. For example, rates of nutrient cycling or productivity may be highly variable at small spatial scales, but this variation is much less at larger scales, because of the integrating effect of spatial aggregation. Similarly, most ecosystem functions are enormously more variable over shorter time scales, compared with longer time scales, which effectively integrate and average these temporal variations. The context of scale is important in the design of monitoring and research programs for ecosystem functions, and in the

selection of appropriate indicators. In such systems, appropriate regard must be taken of shorter- and longer-term, and of smaller- and larger-scale contexts.

4.1.2. Effects of Ecosystem Conditions on Atmospheric Conditions

It is useful to recall that atmospheric conditions are significantly affected by changes in ecosystems as a result of functions that are carried out by elements of biodiversity. For example:

(1) Deforestation causes large emissions of CO_2 to the atmosphere, resulting from the oxidation of most of the original forest biomass. About 1/2 of the anthropogenic CO_2 emission during the past 150 years has resulted from deforestation.

(2) Afforestation results in a substantial removal of CO_2 from the atmosphere. This occurs through the fixing of CO_2-carbon into the organic-carbon of aggrading forest biomass. Afforestation is a strategy that can significantly contribute to reducing net anthropogenic emissions of CO_2, while also achieving substantial non-carbon benefits, including the provision of habitat for indigenous elements of biodiversity.

(3) The treatment of agricultural lands with inorganic nitrogen fertilizers increases the rate of denitrification, resulting in emissions of N_2O, a potent and persistent greenhouse gas.

(4) The development of reservoirs results in increased emissions of CH_4, a potent greenhouse gas.

(5) Changes in ecosystem cover can profoundly affect albedo, evapotranspiration potential, and other variables related to the Earth's energy budget, causing substantial changes in local and regional climate.

4.1.3. The Effects of Atmospheric Change on Ecosystem Functions and Services

The elements of atmospheric change that pose potential risks to biodiversity and ecological functions were given in Section 1.3. Except for chlorinated hydrocarbons, these stressors have both natural and anthropogenic components, which are cumulative in their impacts. Some of the atmospheric stressors pose direct threats to biodiversity through toxicity. All of the atmospheric stressors are potentially important in causing ecosystem damages indirectly, for example, by causing damages to habitat. Here it should be emphasized that these stressors often occur together, and in conjunction with other kinds of stressors such as deforestation, urbanization, industrialization and highway construction. The combined effects of these many stressors on ecosystems are rarely considered.

4.1.4. Responses to Three Questions Posed by R. Slater and I. Burton

(1) Can biodiversity change give an integrated picture of atmospheric change, including an early-warning capacity?

In some cases, this can be accomplished. For example, an appropriately designed climate-change detection program could focus on community-level biodiversity changes occurring at climatically determined ecotones, such as latitudinal or altitudinal tree-lines, or prairie-forest ecotones, or along coastlines (associated with a rise in sea level).

(2) Can atmospheric change provide an early warning of impending changes in biodiversity or ecosystem function?

In some cases, this can be accomplished. For example, an appropriately designed monitoring program for climate could focus on situations in which climatic variables are known to be the primary controlling factors of biodiversity elements or ecosystem functions.

(3) Is the understanding of known or potential linkages of atmospheric change and losses of biodiversity sufficiently well-founded to establish policies towards avoidance or mitigation of damages?

Some of the relationships are sufficiently understood to establish policy and implement actions. This is particularly true of acidifying deposition from the atmosphere, toxic gases, and anthropogenic intensification of the greenhouse effect. This is also true, but to a lesser degree, of depletion of stratospheric ozone and deposition of trace toxics from the atmosphere. The integrated or cumulative effects of environmental stressors are not yet well understood.

4.1.5. Recommendations

4.1.5.1. General Recommendations

1. **Statement**: Biodiversity is a cross-cutting issue, with implications for society and for economic and ecological systems. Assessments of risks to biodiversity require integrated consideration of many issues.

    Recommendation: Develop and implement interdisciplinary frameworks for assessment of risks to biodiversity, and develop strategies to avoid or mitigate those risks.

    Anticipated Benefit: Improved understanding of the causes and consequences of losses of biodiversity, and of ways to avoid or repair those damages.

2. **Statement**: There is a crisis in loss of indigenous Canadian biodiversity.

    Recommendation: Conduct a risk analysis to determine the most important factors involved in losses of indigenous biodiversity in Canada. This analysis should consider factors that pose clear and present risks to indigenous biodiversity, as well as those that are potentially important over the medium- and longer-term.

    Anticipated Benefit: Priorization of actions towards the conservation and protection of indigenous Canadian biodiversity.

3. **Statement**: There is insufficient knowledge about the nature of Canadian biodiversity, including elements of indigenous biodiversity that are at risk.

    Recommendation: Support greater efforts towards the description of biodiversity in Canada, and the determination of factors that cause losses of indigenous biodiversity. These initiatives should involve: (a) completion of a Canadian network of Conservation Data Centres, and continuing support for EMAN (the Ecological Monitoring and Assessment Network), (b) training and subsequent field work of specialists in research on the identification and ecology of biodiversity, and (c) programs of monitoring and research into the causes of environmental change and the consequences for Canadian biodiversity.

    Anticipated Benefit: Better knowledge of Canadian biodiversity, so that its conservation and protection can be pursued from solid scientific knowledge.

4. **Statement**: Biodiversity provides ecosystem goods and services that are required by humans. These represent potentially renewable resources that are critical to the support of sustainable economic systems.

    Recommendation: Support research into the design of ecologically sustainable ways for harvesting and managing of biodiversity resources.

    Anticipated Benefit: Progress towards development of a sustainable economy, while also conserving and protecting indigenous Canadian biodiversity.

5. **Statement**: Biodiversity has intrinsic value. In particular, extinction is non-reversible. Any degradation of indigenous biodiversity is unacceptable.

    Recommendation: Increase efforts towards the conservation and protection of indigenous biodiversity in Canada. Necessary actions include: (1) conduct gap analyses to determine those elements of indigenous biodiversity that are not adequately protected, (2) design and implement an appropriate network of protected areas in Canada, (3) implement more appropriate management of ecosystems outside of protected areas, i.e., manage landscapes and seascapes on an ecological basis, and (4) provide support for all of the above actions not only in Canada, but also in developing countries.

Anticipated Benefit: Increased protection of biodiversity in Canada and elsewhere, along with increased ecological integrity and environmental quality.

4.1.5.2. Recommendations Specific to the Effects of Ecosystem Changes on Atmospheric Conditions

1. **Statement**: Most elements of atmospheric change have both natural and anthropogenic components, which are cumulative in their influence.

   Recommendation: Support research into understanding of the relative importance of natural and anthropogenic influences on atmospheric changes. Particularly important in this regard is the degree of anthropogenic forcing of atmospheric change.

   Anticipated Benefit: Improved understanding of the role of anthropogenic influences, allowing the development of prudent, cost-effective strategies to avoiding unacceptable changes in atmospheric conditions.

2. **Statement**: Some changes in land-use and biodiversity have important effects on atmospheric conditions.

   Recommendation: Increase research into the influences of biodiversity and land-use on atmospheric change, and implementation of appropriate actions. Canadian priorities should include: (1) afforestation to obtain offset-credits for CO_2 emissions, (2) forest conservation to avoid or defer CO_2 emissions, and (3) studies of CH_4 emissions from large hydroelectric reservoirs.

   Anticipated Benefit: Development of more cost-effective strategies towards reducing anthropogenic influences on atmospheric change, with subsequent benefits in terms of protection of biodiversity and ecological functions.

4.1.5.3. Recommendations Specific to the Effects of Atmospheric Change on Ecosystem Function and Biodiversity

1. **Statement**: It is always preferable to reduce exposure to atmospheric stressors than to attempt to mitigate the damages caused to biodiversity and ecosystem functions.

   Recommendation: Support greater efforts towards reducing the intensity of atmospheric and other environmental stressors. This includes reduced emissions of chemicals and changed land-use practices that affect atmospheric quality.

   Anticipated Benefit: Reductions in the intensities of anthropogenic stressors of atmospheric quality and ecological integrity, which will result in fewer losses of indigenous biodiversity, and maintenance of ecosystem functions.

2. **Statement**: There is a pressing need for appropriate indicators of the responses of biodiversity and ecosystem functions to changes in atmospheric conditions.

   Recommendation: Support research into the development of appropriate ecological indicators, and implement these in monitoring programs. Attention should be given to indicators based on: (1) umbrella species that integrate complex information within communities and/or landscapes, (2) functional indicators, (3) composite indicators of ecological integrity, and (4) proxy indicators (such as those derived from palaeoecology).

   Anticipated Benefit: Availability of cost-effective indicators of losses of biodiversity and degradation of ecosystem functions.

3. Statement: Atmospheric changes may be causing important losses of indigenous Canadian biodiversity, and these losses will intensify in the future. These losses are highly regrettable. Vigorous actions are required to avoid further damages, and to repair past damages, where possible.

Recommendations: (1) Maintain or enhance the integrity of extensive monitoring networks and open-access, long-term databases relevant to determining the spatial extent and temporal trends of physical and chemical atmospheric conditions.

(2) Integrate the above recommendation with research into the causes and consequences of losses of biodiversity and degradation of ecological functions. These integrations should be pursued on an extensive basis, and also at sites where research and monitoring are pursued on a relatively intensive basis (for example, at sites within the EMAN). All networks should be rationalized on the basis of such integrations.

(3) Establish sites along gradients of change in atmospheric conditions, particularly those related to climate. One focus should be on ecotones thought to be determined by climatic conditions, such as latitudinal or altitudinal tree-line, or prairie-forest boundaries.

(4) Adaptively utilize the developing scientific knowledge and understanding to produce better, more integrated models of relationships between atmospheric change and losses of biodiversity and degradation of ecosystem functions.

Anticipated Benefits: Improved ability to predict, avoid, and mitigate losses of biodiversity and degradation of ecological functions caused by changes in atmospheric conditions.

4.1.5.4. Recommendations Relating to the Communication of Results

To the Public - The message to the public should be generic with respect to biodiversity, and atmospheric influences should be put into the context of all stressors degrading biodiversity. The statement would be of the form: "There is an accelerating biodiversity crisis in Canada and globally, and positive actions must be undertaken and should be supported by society." This message should be delivered as follows: (1) to the broader public through the mass media, including the Internet and World Wide Web, (2) as part of an integration of environmental issues across educational curricula, (3) within environmental-studies classes, using Canadian curricula, and (4) by fostering ENGOs (environmental non-government organizations), volunteer-action networks, and other community-level partners.

To Policy People and Decision Makers:

(1) The more general message would emphasize the facts that: (a) there is a crisis, (b) its dimensions are cross-cutting across society, the economic system, and natural values, and (c) an integrated, multi-agency, multi-sectoral response is required.

(2) Another broad message would emphasize that Canada has responsibilities as a signatory nation to the Conventions on Climate Change and Biodiversity, and under the Canadian Biodiversity Strategy. Canada must implement the action plans of each of these.

(3) The message focusing on atmospheric interactions would state that the Atmospheric Environment Service is well positioned to contribute to the monitoring and research that is required for dealing with the issues, within a context of integrated actions with other relevant partners.

(4) The specific science agenda that emerges from the present workshop should be communicated to policy and decision makers through a brief incisive summary (the proverbial two-pager).

To Scientists and NGOs - These parties should have easy access to this Workshop Summary Report and the larger Workshop Proceedings, both of which should be widely communicated, e.g. through the Internet and World Wide Web. Communications should be with individual scientists, standing committees and networks. These communications should be pro-active.

To Funding Agencies - There should be direct communications with relevant funding agencies, through personal contact and the Workshop Summary Report.

To Industry - Industrial policy should be influenced by communicating through their relevant associations. Industrial scientists are influenced in the same ways as other scientists. There should be a linkage with certification processes for industrial products.

To a Broader Partnership - All relevant partners, including policy and decision makers and scientists with government, industry, academia, and ENGOs should be involved in two forums: (1) a *Science and Policy Forum on Biodiversity Loss*, and (2) a *Science and Policy Forum on the Effects of Atmospheric Change on Biodiversity Loss and Degradation of Ecosystem Functions*. The forums would be supported by draft versions of: (1) science assessments, (2) policy assessments, and (3) recommended action plans.

4.1.6. Presentations

Short papers were delivered by three speakers, as follows (the papers will be included in the Workshop Proceedings to be published in 1997):

1. Ian Hogg, Environment Canada, "Assessing the Genetic Structure of Benthic Populations in the St. Lawrence River".
2. Wade Bowers: "Biodiversity of Boreal Ecosystems in Newfoundland: Terrestrial Arthropods".
3. Doyle Wells "Ecosystem Processes and Biodiversity in Newfoundland: The Glide Lake Forest Ecosystem Processes and Biodiversity Project".

4.2. REPORT OF WORKING GROUP II: Implications of Atmospheric Change for Landscape Ecology and Biodiversity[10]

Chair: Roger Suffling **Rapporteur:** David Welch **Participants**: Paul Aird, Terry Carleton, Jing Chen, Heather Hagar, David Hik, Tom Hutchinson, Bob Jefferies, Jeremy Kerr, Ted Munn, David Rapport, Robert Rempel, Ian Smith, Anastasia Svirejeva, Ian Thompson, David Wedin

4.2.1. Landscape Ecology: An Introductory Summary

> A *patch* is defined as an internally homogeneous plant community with no spatial differentiation. A *landscape* contains contiguous, interacting patches. A mosaic of landscape types makes up the *regional* scale, and adding up the regions leads to continental and global scales. Walker (1994)

The Canadian landscape, even in its "natural" state, is inhomogeneous, with many lakes, wetlands, rock outcroppings, coastal irregularities, mountains, and ecosystem types. The landscape is where the ecological effects of human activity are most obvious - conversion of forest to agricultural land, forest harvesting by clear-cutting, urbanization, reservoir/hydroelectric dam construction, drainage of wetlands, etc. Over the last 50 years, the human impact on ecosystems at this scale has increased enormously, particularly near large urban areas. The impacts of these long-term changes on biodiversity have been profound in many cases, but sometimes the very diversity of the landscape is a buffer against the widespread effects of society: some of the patches provide suitable refugia for

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[10] *Contributed by D. Welch*

the survival of species during extended droughts, forest fires and pest outbreaks (Mooney et al. 1995).

Of considerable importance in landscape ecology is **gap analysis**, which is the identification of areas where species and communities of species are blocked from migrating to areas of more favourable meteorological and/or soil conditions because of natural or anthropogenic barriers (Hudson, 1991). **Fragmentation** is the process of creating ecological gaps due to agricultural development, urbanization, drainage of wetlands, etc. Gap analysis and fragmentation at the landscape level can be monitored accurately from satellites down to a 1 km x 1 km level of detail. Year-to-year changes in landscape boundaries are of considerable importance.

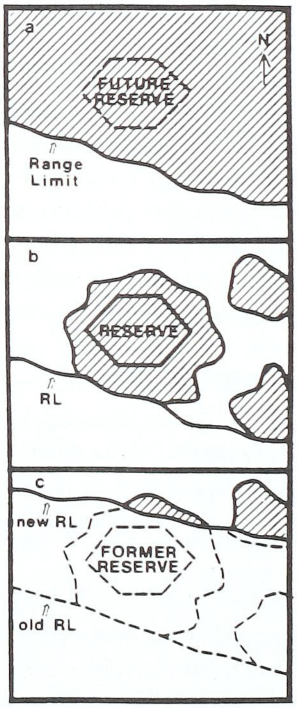
From the policy point of view, there is interest at the present time in the establishment of **corridors** to connect patches and landscapes, to assist in migrations, seed dispersal and habitat protection; see, for example, Mann and Plummer (1993; 1995).

There is, of course, a great need to understand how landscape processes and dynamics determine landscape structure so that interactions with global change can be assessed. This involves both field experiments and models, and intensification of efforts along these lines is one of the major recommendations of this Working Group: see Section 4.2.3.1.

4.2.2. The Effects of Atmospheric Change on Ecosystems and Biodiversity at the Landscape Level

Particularly in the case of large parks and Biosphere Reserves, there is concern about the effects of global change on landscapes and biodiversity (Wilcove and May 1986). Figure 4.1 depicts the possible effects of climate warming on a dedicated Biosphere Reserve.

Figure 4.1 Northward Shift of Vegetation Across a Biosphere Reserve



But landscape ecology is important for many other reasons relating to atmospheric change:

- The landscape scale connects global climate-change scenarios to assessments of many important ecological and socio-economic impacts of such climate changes (the top-down approach).

- Much basic work on ecosystems and biodiversity has historically been on the small scale, and needs to be connected upward through the landscape scale to the global one (the bottom-up approach).
- The environmental assessment process in Canada is usually undertaken at the landscape scale. More and more frequently, proponents of new developments (hydroelectric projects, mines, highways, etc.) are being required to include evaluations of biodiversity changes at the landscape scale in their assessments. How should atmospheric change be factored into these assessments?
- The landscape scale often (but not always) corresponds to the regional land-management scale, e.g., the Lower Fraser River Valley, as well as to natural and human-modified hydrological catchment areas and watersheds. Landscape ecology is therefore of considerable practical importance.

4.2.3. Recommendations

4.2.3.1. General Recommendations

Scale: Whereas ecological data are collected and processed at various spatial and temporal scales, assessments of the impacts of global change on biodiversity, and management of renewable resources accordingly, need to be related to the landscape scale. This is the scale at which many human activities are undertaken, be they in forest management, urban and regional planning, or farm commodity management (e.g. wheat and dairy boards).

Processes: There is a need to understand more about how landscape processes and dynamics determine landscape structure (species composition, habitat, patterns, etc.), so that the likely impacts of global change can be assessed. Over a large area, ecosystems are constrained primarily through climate (mainly as expressed by temperature), secondly through site conditions, then through disturbances. However, climate changes are likely to bring about changes in disturbance regimes, such as the incidence of fire, drought or pestilence.

Urban-Rural Transects: Much glamour is associated with working in remote areas, but resource-management problems are where the people are, in urban regions and in other greatly modified landscapes. Therefore, research should be undertaken on transects outward from urban centres through the rural-urban fringe to the agricultural-woodland transition, or away from mining developments. Some degraded ecosystems will be more sensitive to climate change than ecosystems in wilderness areas although the "noise" level due to many kinds of human influence may be difficult to interpret. Within this context, studies should examine multiple scales from micro- to macro-habitat.

Programme Management: Long-term monitoring and research programmes should be institutionalised to ensure continuity beyond the working term of a particular principal investigator. However, a good national programme is not just a collection of nodes and sites. It should include a strategic plan to co-ordinate otherwise disparate research into unified programmes to foster landscape- and regional-scale studies (Hicks and Brydges, 1994; RSC, 1995, p.32), and to identify research gaps such as appropriate transects as noted above. The Ecological Monitoring and Assessment Network (EMAN) is a good approach to programme integration. EMAN itself requires a firm institutional base to secure it for the long term, rather than depending on the good will of co-operating agencies who may face budget reductions from time to time.

Data Management: There is an urgent need to use national and international standard methods in data collection and processing. Also, data should be thoroughly catalogued, properly archived, and referred to in publications so that their existence is known and so that they can be accessed long into the future. Standards should be catalogued and actively promoted to both meteorologic and biologic communities, perhaps though the work of a standing committee.

Communication: Ecologists must increase communication of their findings and concerns to the general public and managers in industry and government.

Training:
(1) Exchanges of ideas. Interdisciplinary training is essential to understand and solve ecosystem problems. Exchanges of people and ideas are cornerstones of interdisciplinary science. References and manuals aimed at cross-disciplinary audiences are needed in recognition of the many facets of ecosystem science that must often be carried out by small teams. Much of this material could be in electronic form. There should also be more interdisciplinary conferences like the EMAN meetings, the recent Ecosystem Health Conference and the Science and Management of Protected Areas conferences.

(2) Taxonomy. Behind both rapid inventories and calibrated ecosystems there is a continuing need for taxonomy to identify indicator species and species assemblages. For example, there are over 75,000 arthropod species in Canada, and 300,000 in North America. Taxonomy training workshops are needed for experts who would then train other scientists, technicians and volunteers. Supporting products should include illustrated guides using CD-ROM technology.

4.2.3.2. Recommendations Specific to the Effects of Atmospheric Change on Ecosystems and Biodiversity at the Landscape Level

Remote Sensing: Satellites can provide long-term landscape-scale data on photosynthetically active radiation absorbed by plant canopies, net primary productivity, length of the growing season, leaf area index and land cover. The Canada Centre for Remote Sensing currently provides 10-day composite images of these products at 1 km x 1 km resolution for all of Canada as obtained from the Advanced Very High Resolution Radiometer (AVHRR) on board the NOAA satellite. Such information is invaluable for long-term studies of gradual fragmentation of ecosystems, loss of corridors and degradation of habitats, e.g., prairie wetlands (Sample, 1994). The use of remote sensing for other biodiversity-related purposes requires research on key questions such as what species can be detected or deduced from images, and what are species affinities to terrain and spectral characteristics. In this context, some species may be more valuable than others, in the sense of relating to remotely sensible indicators of ecosystem conditions. This may retain a focus on above-ground vegetation despite calls for other kinds of species as biodiversity indicators.

The value of long-term satellite data programmes and products needs to be made clear to remote sensing agencies; otherwise there is a risk of those programmes not being continued. Such data can be used for ecosystem change detection at the landscape level.

Regionality: Similar ecosystems may respond differently in different regions to similar types of stressors associated with atmospheric changes, as well as with land-use changes. Regionality must therefore be included in landscape-scale biodiversity assessments.

Response of Species and Ecosystems to Atmospheric Change: Too much emphasis tends to be placed on above-ground biomass of flora, and there is need for more knowledge of organisms themselves, such as their migration rates, growth and expansion. It is difficult to project ecosystem changes resulting from climate change because of uncertainties over how assemblages of species may or may not be able to migrate together. We cannot simply transpose contemporary ecosystems from equivalent contemporary climates. We also need to disentangle the effects of climate change from those of other human activities such as clear-cutting and other landscape modifications, pesticides and fertilizers, airborne toxics and invasions by exotic species. There is also a need to examine a greater range of indicator species. Candidates are mites and diatoms.

Examination of Biodiversity Hot Spots: Protection of biodiversity "hotspots" cannot be assured by protection at the patch scale (Noss, 1995). During periods of atmospheric change, protection at the landscape scale at least is essential. The threats to biodiversity are broad in scope, yet there is a limit to the public's willingness to follow all the issues and to fund conservation and protection science. This means that priorities must be set on conservation efforts. However, we also recognize the intrinsic value of all species. Therefore we must develop rapid inventory techniques for biodiversity assessment and identification of hot spots. This way, all landscapes and a range of indicator species can receive some attention, not only by scientists but also in some cases by volunteers who wish to participate in monitoring activities. A corollary is the importance of matching such large-area, low-cost rapid inventories to calibrated ecosystems, such as the Experimental Lakes Area and some forest research stations. Such sites should be able to demonstrate the impacts of global change on forestry, agriculture, human and wildlife health.

Monitoring biodiversity at the landscape scale: some emerging principles

1. Species that inhabit only patches in the landscape have a threshold requirement for habitat, below which they face inevitable extinction (long before all of the habitat has been removed). [*Note that atmospheric change is one of the causes of habitat loss.*]

2. Destruction of habitat can cause dramatic loss in biodiversity that is long delayed, non-linear and conspicuous only after substantial habitat disappearance. This means that monitoring programmes and trend analysis may offer a false sense of security that hides the risk of the impacts of further habitat loss.

3. The observed biodiversity patterns or dynamics depend on how long a time period and over how large an area the data are collected. Local census programmes of limited duration may entirely misrepresent the true population dynamics at play.

4. Current biodiversity mapping projects that use GIS will be most useful when they are used to look at dynamics, as opposed to static snapshots, and when they are connected to mechanistic theories that predict population dynamics as a function of landscape attributes.

- Kareiava, P., and Wennergren, U. (1995) "Connecting landscape patterns to ecosystem and population processes", *Nature, 373,* 299-302.

Protected Areas: Social values must be retained in ecosystem studies, such as the interaction between human and landscape health. These linkages will have more influence on public attitudes and policy responses than concentrating solely on the biophysical aspects of global change. Landscape health can be expressed in terms of an array of biodiversity services, such as hunting opportunities or clean water availability. Most habitat loss is irreversible. Even in protected areas there is a gradual decline in habitat quality and species, and this has accelerated since the 1960s, even in the face of conservation efforts. Therefore the "12%" target for protected areas, espoused by the Brundtland Commission, will not by itself protect all species and ecosystem types. Biodiversity protection must be rooted at all levels of society, e.g. in urban design, use of horticultural pesticides, and farming and silvicultural practices. Global change is not at the top of the public's list of concerns, compared to, e.g. employment, living standards, health, security and human rights. Communication with the public is vital to influencing the course of human affairs and global change. Great effort must be made to use common terms and graphic expressions rather than technical language. Once established on public and political agendas, biodiversity protection must be based on specific, objective targets, not just general principles. Only with specific targets can governments and industry be accountable for protection and conservation measures. Much can be done by analysing existing data sets, and communicating the results in socio-economic terms.

Atmospheric Data and Information Needs:

(1) Attributes: The major data and information gaps that ecologists would like filled by atmospheric scientists are measures of extreme events. One example is snowfall and melt-re-freeze events that determine the winter survival of caribou and muskoxen. These should be coupled with estimates of the probability of those extremes. Other examples are: ozone episodes and plant injury; length of the growing season; arctic ice flows and effects on sea birds; night lighting and bird deaths; acid deposition; and albedo.

(2) Scale: To complement landscape-scale ecological studies, there is need for studies of mesoscale meteorology, climatology and air chemistry, i.e. at scales that relate to species' communities. Results would be applicable to land management at the stand, watershed and ecosection scale. In general, there are multiple stressors acting over multiple time and space scales, not just at the synoptic to global scales currently dominating climatology. Decadal averages will be useful, but they should include information about variability and extreme events. This may mean continuous to hourly meteorological observing, seasonal or annual processing and data storage, and annual to decadal analysis and reporting to influence policy and society.

(3) Workshop: A specific workshop is needed on the question of what new data ecologists want from the atmospheric sciences.

Research: The recognition of the landscape level as a priority for research must be reflected in research grants. This means that more emphasis should go on team projects and district-to-regional scale studies, to complement individual investigators working in small areas.

4.2.4. Inventory of Long-Term Ecological Research and Monitoring Activities in Canada

A compendium of 59 long-term ecological research and monitoring activities in Canada was recently compiled for the Canadian Global Change Programme (CGCP) (RSC, 1995, p.41). The full compendium consists of half- to full-page summaries of relevant programmes like field stations, ecosystem-based experiments and monitoring, and national and international research programmes. Examples include the Boreal Ecosystem Atmosphere Study (BOREAS), the International Tundra Experiment (ITEX), and the Northern Biosphere Observation and Modelling Experiment (NBIOME). Members of the Working Group mentioned a number of additional programmes.

4.2.5. Presentations

Short papers were delivered by seven speakers. These papers will be included in the Workshop Proceedings to be published in 1997.

1. Jing Chen, Canada Centre for Remote Sensing, "Ecosystem monitoring from space and its implications for biodiversity."
2. David Rapport, University of Guelph, "What is landscape health?"
3. Terry Carleton, University of Toronto, "Latitudinal trends and boundaries in the Ontario understorey forest vegetation."
4. David Hik, University of Toronto, "Biodiversity and habitat renewal."
5. Jeremy Kerr, York University, "Energy and large-scale biodiversity patterns."
6. Rob Rempel, Lakehead University, "Forest research and monitoring programme."
7. Ian Smith, Agriculture Canada, "Species composition of Canadian ecosystems: integrating historical and ecological perspectives."

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4.3. REPORT OF WORKING GROUP III: Biomes and Sectors Most at Risk[11]

Chair: Richard Elliot **Rapporteur**: Quentin Chiotti **Participants:** Antonio Finizio, Richard Hebda, Geoff Holroyd, Abdel Maarouf, Patricia Roberts-Pichette, Elaine Wheaton.

4.3.1. Introduction

The principal task of this Working Group was to identify biomes and sectors in Canada most at risk to atmospheric stresses. The members brought considerable expertise and knowledge to their task; however, given the breadth of biodiversity across a country as large as Canada, it was inevitable that some knowledge gaps would arise. In preparing this report, some of these gaps have been redressed.

Atmospheric stresses were identified as: acidic precipitation, climate change and variability, stratospheric ozone depletion (increases in UV-B), smog, hazardous airborne pollutants (HAPs) and suspended particulates. After considerable discussion on various biomes across Canada, the following were recognized as being pertinent to the task of the WG: Prairie Grassland, Alpine Tundra, Arctic Tundra, Freshwater Wetlands, Coastal Wetlands/Shorelines, Nearshore Marine, Montane Forests, Coastal Temperate Forest, Carolinian Forest, Boreal Forest, and Aspen Parkland. Sectors were defined as industrial or economic activities: forestry, fisheries, agriculture, water resources, energy, recreation and tourism, then extended to include intrinsic values and human health.

4.3.2. Sensitivity of Biomes to Atmospheric Change

During the course of the discussion on sensitive biomes, the following issues were among the highlights which garnered our attention:

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[11] *Contributed by Q. Chiotti*

- Spatial and temporal scales are very important when examining biodiversity, climate change and other atmospheric stresses. Climate change over the last 10,000 years and acidic precipitation over the last 50 years have already affected and will continue to affect biodiversity.
- *Prairie grassland biodiversity* is influenced by climate variability through the alteration of the phenology of biological events, the periodicity of cyclic events and the number and size of severe weather events. In most cases, the expected effects of long-term climate change, wet/dry cycles, and extreme events, on prairie wildlife are negative. The ability of prairie wildlife to adapt to changing weather patterns varies by species, the size of their populations and the area of native prairie that supports them (Holroyd and Beaubien, 1996). The grassland biome and habitats tend to be the least protected, yet they could also benefit from global warming; however, they face pressure from agriculture and urban development, cattle grazing and invasions of weeds (e.g. knapweed).
- The *arctic tundra biome* is under threat from persistent low-level inversions together with wind trajectories bringing pollutants from Asia and Eastern Europe. These pollutants include radionuclides (from nuclear testing and accidents), heavy metals, mercury and cadmium, and a wide range of pesticides. A serious threat for the future is stratospheric ozone depletion and increasing UV-B. Already lichen damage is occurring in Northern Greenland, attributed to excessive UV-B (Johnsen and Heide-Jørgensen, 1993; de Fabo, 1995).
- Some regional biomes are particularly at risk to climate change, e.g., *freshwater wetlands* and the *coastal temperate rainforest* in British Columbia. *Prairie wetlands* and *aspen parkland*, and perhaps the *boreal forest*, are also threatened from fire, pests and diseases. The situation in Atlantic Canada is difficult to assess, as aerosols downwind from industrial American sources may counteract the effects of global warming, producing a slight cooling. Changes in Atlantic terrestrial systems are not clearly related to climate change, but rather to acid rain. The East Coast fishing biome is a complex system; the current crisis is influenced by an influx of colder water and by overfishing. There are similar declines in marine resources along the West Coast with a corresponding rise in aquaculture, whose production system is very sensitive to atmospheric stresses.
- An absence of suitable soil characteristics and habitats may prevent species from moving northward when climate change occurs (e.g. Carolinian forests, agriculture); planting of seedlings in especially prepared soils may be needed in some areas.
- Biomes in southern Ontario are highly vulnerable to atmospheric change due to human development (highways, suburbia, etc.).
- Palaeo records suggest that some biomes are more sensitive to climate change than others. For example, small alpine areas are greatly at risk; large one not so much. Mid-size biomes may not be greatly affected in some cases.
- *Freshwater wetlands* are particularly vulnerable to atmospheric stresses.

The W/G developed a matrix of biomes and atmospheric stresses. Before doing so, however, the Group agreed on two qualifiers that would shape the analysis. First, a biodiversity goal is to restore and maintain indigenous biodiversity. Second, there is tremendous regional variation in biodiversity, atmospheric stresses and the interactions amongst them. Appreciating the regional specificity of many of the sensitivities, the W/G agreed that it would only be possible to identify general patterns, recognizing that further regionally specific studies are needed.

The W/G focused on biome sensitivities using a scale of 0 - 3, with 0 representing zero risk (or benign/favourable effects) and 3 representing high risk (or severe impacts). In cases where there was some uncertainty (e.g. due to lack of knowledge), a question mark (?) was recorded. In most such cases, the actual risk could be higher than estimated.

Of the 11 biomes identified as being at risk, Freshwater Wetlands (with a score of 12) were judged to be at the greatest risk to atmospheric stresses. Arctic Tundra, Prairie Grassland, Carolinian Forest, and Montane Forest and Boreal Forest were next on the list, scoring 9, 8, 8, 7, and 7 respectively, while Nearshore Marine and Aspen Parkland were deemed the biomes least at risk. Note however that these values do not necessarily reflect the 'relative' impacts of each stress, nor the synergistic effects that could arise. For example, given the location of the Coastal Temperate Forests, the atmospheric stresses associated more commonly with urban areas (e.g. Smog, HAPs, Particulates) will likely have a minor effect; however, impacts from climate change are expected to be high, and by themselves could have a tremendously adverse effect on this biome. Similarly the interaction of Climate Change, HAPs and especially enhanced UV-B radiation is likely to have a profound adverse effect upon Arctic aquatic and terrestrial ecosystems (de Fabo, 1995).

Table 4.1: Risk to biodiversity in each biome type to each of the six atmospheric stresses (Note that risk combines sensitivity and the likelihood of the event occurring. (0 is zero risk; 1 is slight risk; 2 is moderate risk; 3 is high risk.)

	Acid	CC	UV-B	Smog	HAPs	Part.	Total
P G	0	3	1?	1?	1?	2	8
Al T	0	3	2?	0?	0?	0?	5
Ar T	0	3	3	0	2	1	9
F W	3	3	3	0?	1?	2	12
C W	0	3	2?	0	1?	0	6
N M	0	2	1?	0	1?	0	4
M F	1	3	2?	1?	0	0	7
C T F	0	3	1?	1?	0	0	5
C F	1?	3	0?	2	1?	1?	8
B F	3?	3?	1?	0	0	0	7
A P	0	3	0?	0?	0?	0	3
Total	8	32	16	5	7	6	

Biome type:

P G: Prairie Grassland
Al T: Alpine Tundra
Ar T: Arctic Tundra
F W: Freshwater Wetlands
C W: Coastal Wetlands/Shorelines
N M: Nearshore Marine
M F: Montane Forest
C T F: Coastal Temperate Forest
C F: Carolinian Forest
B F: Boreal Forest
A P: Aspen Parkland

Atmospheric stress:

Acid: acidic precipitation
C C: climate change and variability
UV-B: stratospheric ozone depletion
Smog: smog
HAPs: hazardous airborne pollutants
Part: suspended particulates

Climate change/variability was deemed to have the greatest overall impact upon the eleven biomes, having a severe adverse effect on all types, with the exception of Nearshore Marine, with only a moderate effect. UV-B radiation was the second most significant atmospheric stress, although the W/G's estimates were largely conjectural, with further research necessary to ascertain the full impacts. Similarly, there is a significant knowledge gap regarding estimating the effects from smog, HAPs, and particulate matter. There is considerable knowledge on acidic precipitation, and further effects from this atmospheric stress are likely to be relatively minor, except in specific regions or on a localized basis (Rodhe et al., 1995). In some biomes, however, acidic nitrate deposition could have a neutral, if not positive, impact (Hutchinson and Meema, 1985).

Table 4.2: Risk to each sector from changes in biodiversity due to atmospheric stresses. (0 is zero risk; 1 is slight risk; 2 is moderate risk; 3 is high risk.)

	Acid	C C	UV-B	Smog	HAPs	Part.	Total
Agri (indigen.)	0?	1	0	0	0	1?	2
Agri (managed	1	1	1?	2	0	1?	6
For	1	3	1?	1	0	0	6
Fish	3	3	1	0	3	0	10
Water	1	3	0	0	2	1	7
Energy	0	1	0	0	0	0	1
Rec/T	1	2	0	0	1	0	4
Int. V.	1	3	2	0	1	0?	7
Health	1	3	1	1	1	1	8
Total	9	20	6	4	8	4	

Sector
Agri: agriculture
For: forestry
Fish: fisheries
Water: water resources
Energy: energy
Rec/T: recreation and tourism
Int. V.: intrinsic values
Health: human health

Atmospheric Stress
Acid: acidic precipitation
C C: climate change and variability
UV-B: stratospheric ozone depletion
Smog: smog
HAPs hazardous airborne pollutants
Part: suspended particulates

4.3.3. Sensitivity of Sectors to Atmospheric Change

Table 4.2 shows the risk to each human activity sector from changes in biodiversity due to increases in each of the six atmospheric stresses. The fishing industry (scoring 10 out of a possible 18) was identified as the sector most at risk. Human Health, Intrinsic Values and Water Resources were also deemed to be at some risk, scoring 8, 7 and 7 respectively. Energy and Agriculture (Indigenous biodiversity) were judged to be relatively insulated from atmospheric stresses. In the case of the homogenized biodiversity of modern commercial agriculture, the risk is higher. Wedin (this Workshop) and Tilman et al. (1996) have demonstrated that higher biodiversity in Minnesota grasslands is associated with greater sustainability and productivity. In many regions of Canada, in particular the Prairies, southern Ontario and the St. Lawrence lowlands regions, commercial agriculture could be adversely affected by climate changes (Wheaton, 1994; Smit, 1995), as well as other atmospheric stresses downwind from urban and industrial centres. [Chamiedes et al. (1994) estimated that excluding the effects of climate change, 10 to 35% of the world's grain production will be at risk by the year 2025 due to increased intensity of surface ozone episodes.]

As in biomes, climate change had the highest overall impact upon sectors, scoring 20 out of a possible 27. Acidic precipitation and HAPs were the next most damaging stresses. Some uncertainties also exist, but considerably fewer compared to those which affect biomes.

4.3.4. Monitoring

Monitoring strategies need to be developed for the biomes/sectors most at risk, monitoring both stressors and impacts. Monitoring will enable the detection of changes in biodiversity due to atmospheric change, and will help develop strategies to adapt to, or accommodate, these changes. There is a need to monitor atmospheric characteristics and biodiversity, specifically timing, abundance, productivity and mortality. There is also need to build upon existing data sets, and continue long-term monitoring.

Special emphasis should be given to monitoring at sensitive sites (where big changes are expected), e.g. in the articles where UV-B is expected to increase, and in relict terrestrial and freshwater habitats in the Mixedwood Plains Ecozone of southern Ontario (see box). In addition, baseline sites should be used to monitor biodiversity where no or little change is expected.

Monitoring programs should also include atmospheric studies beneath the canopy, not just from towers.

Monitoring should be undertaken by a wide spectrum of people, ranging from scientists to members of the general public (volunteers).

The Federal Government should play a strong role in co-ordination, establishing standards, leadership, etc.

> Unique plant and animal communities are associated with relict terrestrial and freshwater habitats in the Mixedwood Plains Ecozone of southern Ontario. Climatic fluctuations during the past five thousand years have resulted in the spatial segregation of populations of species restricted to special habitats such as alvars, fens, sloughs and small lakes from their historical distribution centres in the Carolinian Zone of the eastern United States. Human development of the Mixedwood Plains for intensive agriculture, urbanization and transportation corridors has further fragmented the distributions of many of these species to the extent that their Canadian populations are now vulnerable to extirpation in the event of even small climatic changes.
>
> Ian Smith, Agriculture Canada (pers. commun.)

4.3.5. Communication

In the area of communication and education, it is necessary:

- to inform the public of atmospheric change effects on biodiversity and persuade the public of the need to implement adaptive strategies;
- to involve the public in monitoring and conservation;

- to integrate atmospheric change and biodiversity issues into school curriculae and educational venues (e.g. Boy Scout programs, science fairs);
- to extend "hands on" experience with biodiversity (e.g. field trips, demonstrations);
- to put public education in an understandable form, drawing upon Canadian examples wherever and whenever possible;
- to inform ourselves (e.g. through workshops like this), in addition to the public;
- to involve decision makers, such as Deputy Ministers and Assistant Deputy Ministers.

4.3. Presentation

Geoff Holroyd, Canadian Wildlife Service and Elisabeth Beaubien, University of Alberta "Effects of Climate Variability on Prairie Biodiversity".

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4.4. REPORT OF WORKING GROUP IV: Socio-Economic Consequence and Policy Implications on Biodiversity/Atmospheric Change[12]

Chair: Ian Burton **Rapporteur:** Peter Timmerman **Participants**: Alex Alusa, Tom Brydges, Lara Cartmale, Ross Glenfield, Beverley Hale, Chris Henschel, Nicola Mayer, Jeff McNeely, Flora Naadafi, Nigel Richardson, Rodney White.

4.4.1. A Framework for A Scientific Paper: "Elements of A Socioeconomic Research Strategy for Responding to Changes in the Atmosphere and Biodiversity"

The WG decided that a useful way to begin was to develop a framework for a scientific paper elaborating a socioeconomic research strategy relating to atmospheric/biodiversity changes. In the course of the discussions that followed, WG participants made a number of valuable oral and written comments that seemed worth quoting to give a flavour of the discussions and the various concerns expressed. These quotes are given below in boxes without attribution. The phrase "atmospheric changes leading to biodiversity changes" will be abbreviated throughout to AC/BdC.

> *"Socioeconomics is the key to the situation we face -- if we do not get the socio-economic strategy right, the rest will not work."*

The Table of Contents for the proposed scientific paper, with some explanatory notes relating to each Section, is as follows:

1 Introduction

This Section would set out the relevance of the social sciences and policy choices, and stress in particular the need to clarify the ethics and values we are trying to protect in coping with environmental change. An appropriate strategy would also have to relate to multi-sectoral impacts and responses, including (among others) agriculture, fisheries, forestry, wildlife, health, and international trade, and their interrelationships. There is no single socio-economic integrated model available for the various actors and decision-makers, nor is one necessarily what is required. We need ways of demonstrating the linkages between the array of issues, and in particular the linkages between human behaviour and global change.

2. Current atmospheric change/biodiversity change issues

This section would set out the seriousness, and the implications for socio-economic systems, of the biodiversity changes caused or influenced by atmospheric changes. Among the issues raised are:

- Are there differences between the socio-economic impacts of atmospheric change and those of biodiversity change?
- What are the projected socio-economic impacts from AC/BdC according to the models?
- Are there existing examples of socio-economic impacts from AC/BdC, and what can we learn from them?

[12] *Contributed by P. Timmerman*

3. Limitations of current socio-economic approaches and strategies

> *"Because our knowledge of the interactions of AC/BdC is highly uncertain and will remain so, we must develop a multiple-option experimental strategy to encourage and facilitate change, and to become more adaptive."*

This Section would describe both the current implicit socio-economic strategy of modern society and the received approaches to analysing the appropriate responses to environmental change. The current overriding socio-economic strategy of "trying to keep things constant" or even to move to an "improved *status quo*" is only sustainable in the short term. Since scientific knowledge will remain uncertain, it is vital to support adaptive, experimental management. If "management" is "directed change", we need to consider both slowing the rate of change of natural systems (the slower the rate of change, the more our ability to adapt to it increases), and improving our intrinsic adaptive capacity. Our ability to adapt is not very robust.

When we look at the socio-economic models currently deployed to explain the relationship between environmental change and socio-economic behaviour, we find that there are numerous problems including:

- a prevalence of linear (one-way impact flows from ecosystem to social system) vs. cyclical models of interacting systems
- scale problems: e.g. local socio-economic systems have feedbacks that make them often respond more intelligently to relevant information than do global systems
- limitations of forecasting, extrapolation, and future discounting as ways of coping with impending change
- ethical considerations that are elided in favour of "rational economic choices".

A socio-economic research model needs to be developed which will be more complementary to an adaptive strategy: the current socio-economic approaches reinforce a brittle "sustain the *status quo*" strategy.

4. What are society's goals and targets?

> *"How much biodiversity is "enough" (i.e., what is the endpoint or target)? And can we reach an international working consensus on a realistic endpoint towards which action plans can be developed?"*

This Section could begin with a discussion of the history of IUCN's 12% target (i.e., 12% protected land for each country), which was derived by doubling the existing amount of protected land. There are other examples of pragmatic targets (e.g. the Toronto targets for climate change) which are a combination of what is needed and what is do-able. We might also have to develop (as in the ozone convention) a "rolling endpoint" as information improves or the situation deteriorates. One suggested goal is: "We should not lose the capacity to adapt to change", but that raises questions about whether the vagueness of the goal threatens valued species or spaces. Among the issues to be considered are:

- How well do we currently measure and monitor biodiversity change, and will this improve?
- What kind of indicators or targets for individual sector performance could be developed?
- Is the Biodiversity Convention signed at Rio robust enough to support the delineation of scientific and political targets more specifically?
- What are we trying to protect, e.g. are species merely easily identifiable surrogates for adaptive capacity?

5. The human element

> *"Changing human ways and human thinking is imperative in reducing anthropogenic change and the loss of biodiversity."*
>
> *"Reliance on the price mechanism to improve human behaviour with regard to environmental impacts is incomplete because human improvements can and do occur when appeals to social solidarity are made, e.g. blue box programs."*
>
> *"Politicians avoid regulating (or influencing) human behaviour when the personal costs to consumers - their constituents -- would be high e.g. 4 x gasoline price to reduce tropospheric ozone. Therefore we need to find other means to influence people, such as education."*

If we are to change human behaviour or restructure human needs, we need to consider more than economic motivations. Of course, we do need economic incentives, but we also need:

(a) Education: How do we influence the voting population, and succeeding generations of voters? Educators need to be added to the strategic mix of people involved.

(b) Deliberate infrastructure planning: Not only are governments significant purchasers, but they can also act as exemplars for alternatives. Their role as regulators need not be just overt, but they can also influence long-term infrastructure development, promoting or retarding adaptive change.

(c) Improving the availability of alternative choices: Governments (and others) can be used to promote alternative choices that are not currently on the market or that are in pre-market development. It is worrisome that global homogenization of cultural biodiversity is currently taking place, undermining the range of adaptive responses and the available information woven into traditional ecosystems.

(d) Providing better information, and better links between that information and potential impacts: If we provide people with more and better information, they may alter their behaviour.

(e) Supporting lifestyle changes: One strength of the environmental movement to date has been in linking local/personal behaviour to global changes. This needs to be encouraged and articulated in terms of the AC/BdC issues.

6. Ethics

One of the central questions explored by the WG was: What kinds of values and ethical systems are:

(1) involved in the ethical valuing or understanding of biodiversity itself? and

(2) at stake or in conflict generally over this issue, particularly equity issues about costs and benefits?

Why do we want to preserve species - is it for utilitarian reasons? Because species have intrinsic value? In any event, do we want to save species or ecosystem functions? Some argue that what we want to preserve is the integrity or adaptive capacity of ecosystems. Others argue that it is the restoration and maintenance of indigenous biological diversity. Some argue that we need to preserve both ecosystem functions and species integrity, and that the polarized dichotomous debate is a reflection of scientific or disciplinary histories.

There are varieties of environmental or ecological ethics that can be brought to bear on this discussion, ranging from the recognition of human-centredness as a priority all the way to Gaia-centrism which would consider human well-being as marginal or actively hostile to the rest of life on earth. Another relevant ethical area is the development of guiding principles. For example, we could argue that because we know so little about ecosystems and how they function, we should follow the precautionary principle.

We also need to examine the distribution of costs and benefits over the short and long term for different sectors of the community (inside and beyond Canada) from an ethical perspective. We need to ask whether we are concerned only for what is good for Canada in the short term; or do we have concerns for the rest of the world (and Canada) over the long term. What are our global responsibilities? What is the relationship between our commitments to the Biodiversity Convention and our Canadian biodiversity strategy?

If we see biodiversity in part as an information issue, then how are we to deal with the public/private information/intellectual property issues, i.e. where do we draw the boundaries, and who gathers and distributes the information?

7. Economic issues

> *"The inclusion of full-cost pricing, to cover externalities, should be one of the methods of responding to atmospheric change and the loss of genetic diversity, species and populations at all levels."*
>
> *"One of the problems is the use of financial subsidies both nationally and globally in resource sectors, causing continued maladaptive practices as well as not allowing these systems to adapt to change."*

What are the appropriate economic theories and instruments for AC/BdC responses? Standard economic theory has difficulties with the very long term, and with environmental externalities, both of which are central issues in this case. How do we deal with risk and uncertainty? There is general agreement that "honest prices" will improve or change consumptive habits, but how to reach those prices is controversial. There is as yet no agreement about a system of national environmental accounting or how to consider biodiversity as capital stock.

> *"The role that international trade plays in influencing the changes in forests, ecosystems and therefore in reductions in biodiversity and increases in greenhouse gas concentrations needs to be studied, and modalities for influencing it to bring about sustainable exploitation of resources determined."*

Trade/atmospheric change/biodiversity are strongly linked, and could be made central to Canada's response to this issue. But because this goes against the traditional narrow mandates of negotiators, it would need to be carefully reasoned.

8. Institutional issues

Of further concern is how an integrated biophysical response to the situation that we face would be complemented by a dis-integrated institutional context. There needs to be much more cross-sectoral work, determining where biodiversity changes would have their impacts. This section of the paper would also set out the global context, including changes in biodiversity and strategic responses elsewhere, as well as laying out the relevant laws, regulations and international conventions to which Canada is a party. It is important to stress Canada's links to global strategies (e.g. our foreign policy with regard to genetic biodiversity), and the advantages of international accords for ensuring that there is not an unequal distribution of costs and benefits of responding to changes.

A special issue raised by the Working Group was ensuring that actions (such as tree planting) designed to assist in solving another issue (such as rising CO_2 concentrations) should not threaten biodiversity, and should be supportive of the objectives of the Biodiversity Convention.

9. An array of strategies

In this final section of the paper, the idea would be elaborated that an array of strategies would be preferable to a single integrated strategy. How would we get to a publicly supported array of strategies? Could we generate a coherent vision of the long-term targets and goals of each strategy, as well as the shorter term benchmarks and indicators, in support of the overall desire to sustain biodiversity in the face of impending atmospheric change? Further, while supporting an adaptive strategy or strategies for change, we should not lose sight of mitigation strategies. We need to "anticipate and prevent" as well as to "react and cure". There is also a need to relate not just new social science methodologies to an adaptive, experimental approach, but also to rethink the biophysical science agenda. What would be relevant case studies or "experimental plots" for our strategies?

A central concern, given the relative newness of the AC/BdC issue, is the communications strategy. Apart from coping with citizen illiteracy about biodiversity, we need to recognize the scientific illiteracy among experts about what is relevant in other disciplines. It is important that the kind of meeting represented by this Workshop continue, and future meetings include additional disciplines (e.g. industrialists, economists). Substantial language difficulties need to be overcome quite early in further collaboration, not only concerning ethical language but also differing ideas of integration, ecosystem resilience, etc. The scientific paper should consider various relevant definitions for common use.

> *"As a non-scientist, I see the central issue as making scientific knowledge effective - i.e., acted upon. Clearly this isn't happening, except perhaps spasmodically. There is a wide gap between "knowing" (however incomplete) and "doing". (The cod stock case is a good example.) So a key research area of the "soft" sciences, e.g. psychology, sociology, political science, but also perhaps business management, is how to close this gap and get the scientific knowledge acted upon. Communication is needed, but we need more than communication."*

4.4.2. Possible Response Strategies and Their Implications

The main recommendation of the WG is that the various options or choices of strategy for responding to atmospheric change and biodiversity should be laid out in an informed and publicly accessible fashion, using as a model, the Table of Contents for the proposed scientific paper discussed in Section 4.4.1. These options would form a template for socio-economic research, as well as for some of the biophysical research needed to determine what the best alternatives would in fact be. To examine this more closely, the Group examined the strategies mapped out in Burton and Timmerman's paper presented at the Workshop (see Figure 4.2). The Group suggested that in each of the 6 possible strategies (2 were added in the course of discussion for illustrative purposes), if one concentrated on that strategy (either alone or in association with others), then the following issues might be highlighted:

(1) What would concentrating on *in situ* protection mean? (upper left, Fig. 4.2)
- Priority would be given to designating a large number of new conservation sites, linked by corridors.
- There would be a need to partner with parks authorities in Canada and the U.S.
- Management plans would need to include lands surrounding parks.

- A focus of attention would be the need for serious reductions in other stressors.
- This strategy would promote much more emphasis on mitigation of atmospheric change.
- There would need to be a calibration of when "adjustment" capacities had reached their limits.

(2) What would concentrating on an "economic conservation" strategy mean? (upper right, Fig. 4.2)
- Serious attention would have to be paid to deciding about the roles of public/private information, property rights, etc., as these are crucial to efficient economic activity.
- Further support would be given to comprehensive gene banks.
- There would be more efficient application of standard "economic tools" to increasing productivity, etc.
- Legal/business/international law research would need to be strengthened.
- National ecological accounting (for ecological capital, at least) would have to be seriously addressed.

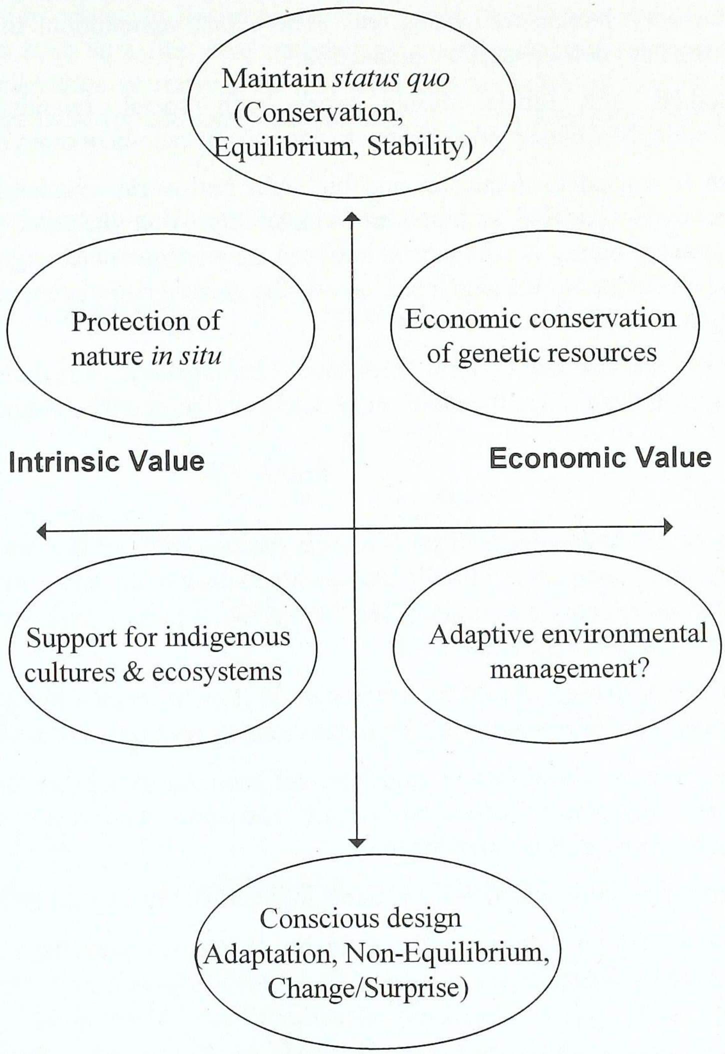
(3) What would concentrating on "adaptive environmental management" (AEM) mean? (lower right, Fig. 4.2)
- The watchword would be: "Tools not rules" -- but what would be the tools?
- Emphasis would be placed on experiments.
- Research would need to explore where AEM had worked.
- There would be a stronger emphasis on local feedback mechanisms, monitoring, etc.
- Politically, there would need to be a rethinking of how to relinquish "control". In addition, it would be stressed that "Adapt does not mean give up".

(4) What would concentrating on "supporting indigenous peoples/ecosystems" mean? (lower left, Fig. 4.2)
- It would be important to identify good and bad indigenous practices.
- Emphasis would be placed on supporting and recovering traditional ecological knowledge.
- Much more research would be needed into common property regimes.
- Responsibility *and* resources would be devolved.
- We would have to learn about sustainable systems designed not to produce “surpluses”.

(5) What would concentrating on the *status quo* mean? (top oval, Fig. 4.2)
- It would mean an intensification of current trends.
- The focus would remain on short-term sustainability.
- The expected gains and losses would have to be pointed out.
- We would have to accept introduction of exotics, and other biophysical changes already happening in Canada.
- It would be important to take note of what is happening elsewhere in the world as an early warning of what might happen here later.
- We would muddle through (perhaps).

(6) What would supporting "Conscious Design" mean? (bottom oval, Fig. 4.2)
- We would shift from "restoration ecology" to "creation ecology".
- There would be deliberate introduction of relevant exotics.
- We might conceptualize Canada as an international zoo or refuge.
- A more stringent planning/zoning system might be introduced, and Canada would become Denmark West or Singapore East.
- A provocative question is: Are we involved in a Conscious Design strategy of our ecosystems already?

Figure 4.2 **An array of strategies for responding to atmospheric change and biodiversity,** *presented by P. Timmerman and I. Burton, this workshop.*



4.4.3. Recommendations

General

1. The various options or choices of strategy for responding to atmospheric change and biodiversity should be laid out in an informed and publicly accessible fashion. The options should be "informed options", including: the reasoning behind each alternative; reasonable cost estimates and potential benefits of each approach; the ethical underpinnings; and the outcomes that could be expected. To reach this goal we need research to fill in the "information gaps". The recommendations below and comments relate to this.

Research

2. An inventory should be prepared of potential scenarios for atmospheric change possible in the next 50 years, together with the consequences for biodiversity, and the socio-economic implications.

3. A more careful and extensive exploration is required of what we value/what is valuable in the atmosphere-biodiversity debate. It was noted that there had been a number of disagreements about whether we were out to protect species, ecosystems, functionality, productivity, human well being, etc. The ethical assumptions that different groups were working with needed urgent clarification.

4. Ecologists and others should work with social scientists to connect natural adaptability/resilience/ productivity to equivalent socio-economic conditions.

5. There is a need to document and highlight real-world examples of how environmental improvement has led to increased adaptability (i.e. increased options, etc.) of socio-economic systems. A comparison between the environmental degradation of East Germany vs. West Germany was suggested, as was the generic rise of ecotourism as a supplement to, or replacement for old industries.

6. Inter-disciplinary and sectoral links should be expanded to include engineering, the health sciences, industry, and the main social sciences (including economics).

Policy

7. Because the hodgepodge of jurisdictions dealing with natural resources makes a coherent policy for conservation virtually impossible to design and carry out, except occasionally on a small scale, there is an urgent need for a study of possible measures that could be taken to improve the present situation.

8. Practical guidelines should be developed on how to include biodiversity considerations in environmental assessments and cumulative environmental assessments.

9. The sustainable development guidelines for each department/sector (initially in the Federal Government) should include biodiversity and atmospheric change. We need to research and assess how best to carry this out.

10. A broader definition/mandate for managing biodiversity should be articulated.

11. There should be a move away from an overly (or narrowly) preservationist view of managing biodiversity.

4.4.3. Presentation to the Working Group

Nigel Richardson, "Responding to Atmospheric Change: Integrated Land Planning and Management".

4.5. REPORT OF WORKING GROUP V: "Self-organizing Ecosystems"[13]

Chair: Roger Hansell **Rapporteur:** Brad Bass**Participants:** Jae Choi, Ian Craine, Richard Fleming, Nina-Marie Lister, Henry Regier, Eric Taylor, Ron Williams

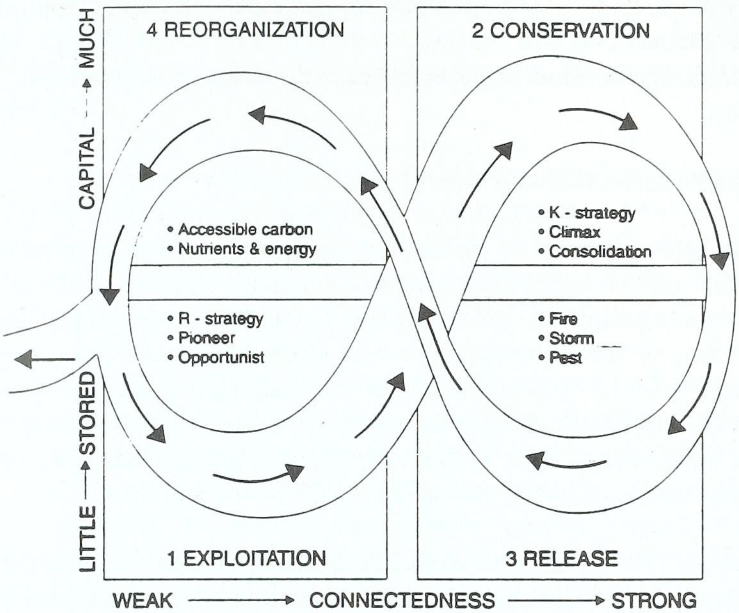
4.5.1. Self-Organization of Ecosystems: A Brief Introductory Essay

Holling's Four-Box Model (also called the Figure-Eight Model)
Holling (1986) reviewed a number of resource management case studies involving situations where an ecosystem collapsed or was seriously damaged. He then formulated a conceptual model of

[13] *Contributed by B. Bass*

ecosystem dynamics featuring discontinuous change as an internal property of the systems that he described and he provided insight as to when such an event would occur. The model included the two functions that determine ecosystem succession: an *exploitation* function related to r-strategists and a *conservation* function related to K-strategists[14] . A third function is one of *discontinuous change* caused by events such as a fire, pest outbreak or a climatological extreme. The fourth function is one of *reorganization* or renewal as resources that are released through the previous change are now made available for the exploitation function. The four functions are shown in Figure 4.3.

Figure 4.3 Holling's four-box or figure-eight model (Holling, 1986)



The third function (discontinuous change) occurs with increasing connectedness and energy storage in a maturing ecosystem. The connectedness becomes the "backcloth" (Atkin, 1978) that allows the rapid spread of a disturbance resulting in an abrupt change in the system. Holling terms this *creative destruction* after Schumpeter (1950). Although massive disturbances may cause significant losses both in terms of area and species, the previously accumulated yet unavailable energy is now released. This stored capital is made available through decomposition and retained through mechanisms, some of which are the colloidal behaviour of soil, rapid nutrient uptake by the remaining vegetation and reduced rates of nitrification (Marks and Bormann, 1972).

In this connection, ecosystems are *lumpy* in space and in time, and this is an essential characteristic of *ecosystem integrity*[15] (Holling 1995, Kay 1994). The processes described by Holling's model occur over a range of different spatial and temporal scales. Understanding how processes at different levels interact requires an understanding of how the four-box model operates at these different scales. In fact, another implication of lumpiness is that the model shown in Figure 4.3 is

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[14] In the early stage of an ecosystem's development, the system is dominated by prolific short-lived and fast-growing species which have been designated as r strategists. In the late stage of development, less fecund, long-lived and slowly-growing species dominate; these are called k strategists.

[15] Ecosystem integrity is defined as the healthy functioning of the various components under current conditions, the ability to cope with stress, and capability to self-organize (Kay, 1994).

concurrently operating at these different scales, and the patterns are out of phase with each other, i.e., interactions between processes at different scales are non-linear (Holling 1995).

Thermodynamic Analysis of Ecosystem Dynamics

Next we review the *ecosystem approach* (see, for example, Schneider and Kay, 1994) and the evaluation of non-linear systems in ecology (Hansell et al., 1997). This review is very brief, and many of the theoretical results require testing in actual ecosystems. Schneider and Kay (1994) applied a thermodynamic analysis to ecosytems by extending the second law of thermodynamics to account for open systems that are not in equilibrium. The second law can be stated in various ways (Sussman, 1972) referring to isolated systems:

- Heat flows spontaneously from a hot object to a cooler object, and not in the reverse direction.
- All possible spontaneous changes increase the disorder or entropy of the universe.

Essentially, all systems move from order to disorder.

This does not account for living systems in which order appears to emerge from disorder. These open, non-isolated systems can be maintained, even as externally applied gradients force these systems to positions far from equilibrium. Schneider and Kay (1994) proposed a refinement to the second law which states that as open systems are moved away from equilibrium, they attempt to resist and dissipate the gradient. As the gradient increases, a system can draw on more sophisticated mechanisms including the emergence of new structures (self-organizing processes) to dissipate the increase in input energy, which effectively reduces the gradient. The new structures which serve to dissipate the increased energy are called dissipative structures.

Nicolis and Prigogene (1977, 1989) demonstrated that dissipative structures self-organize as a result of small instabilities. These small instabilities lead to irreversible bifurcations, and the change is abrupt and not predictable. If the system trajectory is mapped in phase space, which is defined by the rates of change in at least two variables (excluding time), the trajectory may shift from one attractor to another. [An attractor is a region in state space to which the system is drawn following a disturbance.] If two attractors share an abrupt boundary, then small instabilities may cause the system to shift to this neighbouring attractor. Because the exact location or even the existence of these attractors may not be known, the change is often viewed as sudden and unpredictable (Hansell et al., 1997).

Dissipative structures emerge or self-organize in a narrow window where the energy input is high enough, but not too high (Kay 1994). If the energy input falls below a minimum threshold, the structures cannot emerge, or existing structures cannot be supported. If the energy input crosses a critical threshold, it overwhelms the ability of the organized structures to dissipate the energy and remove the gradient. At this point the behaviour of the system *appears to be* highly unpredictable or *chaotic*. In fact the system boundaries, i.e. the basin of attraction (Hansell et al. 1997) are still predictable, assuming that the basin can be described in phase space.

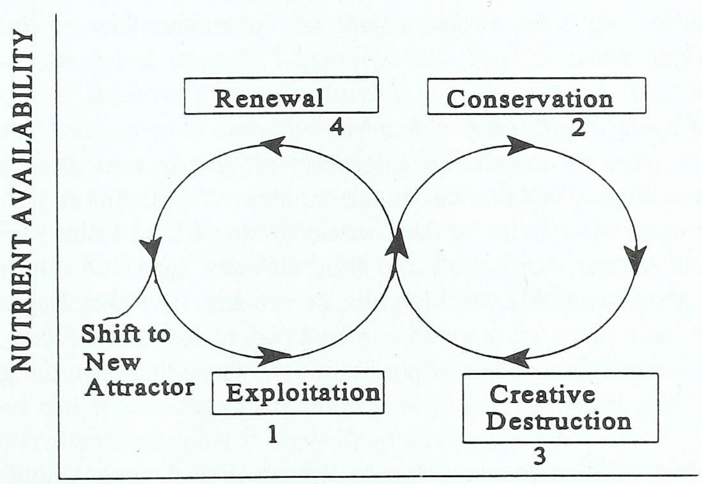
In a living system, the ability of an incoming gradient to establish disorder is decreased by increasing system throughput and by degrading or dissipating the energy input. Schneider and Kay (1994) view ecosystems as dissipative structures organized to degrade energy. As a corollary, the material flow-cycles in the ecosystem tend to be closed to maintain the supply of material that is necessary for the energy-degrading process. The net effect of any evolutionary or adaptive strategy increases the potential for the system and its components to survive, if the net effect is to increase the ability to degrade incoming energy. As ecosystems develop, this ability should increase, and this can be observed through the emergence of more complex structures with increased diversity and more hierarchical levels.

This thermodynamic perspective can be applied to Holling's four-box model (Kay, 1994). Holling's cycle is an attractor. It is a trajectory mapped in a phase space defined by changes in connectedness and nutrient availability (Figure 4.4). The four stages and functions described by Holling represent the response of an ecosystem to changes in the external gradients imposed on it. The gradients across an ecosystem can be grouped into flows of energy, nutrients and information. In the movement from the decomposition and retention of nutrients to exploitation, changes in the availability of nutrients, energy or information could shift the ecosystem to a new attractor. Thus the movement from the decomposition and retention of nutrients to exploitation could be viewed as sharing an abrupt boundary with another Holling cycle. This second Holling cycle is often illustrated as a bifurcation before exploitation begins, and is representative of a different type of ecosystem. Biodiversity plays an informational role, in that it preserves a number of adaptive strategies to stress.

Information is not only contained within the biodiversity represented in a particular ecosystem, but it exists at hierarchically larger scales and acts as an external constraint on system development. For example, after a fire, species can migrate into the burnt-out areas. These species may play catalytic roles in the assembly of the climax community, but may not be permanent residents in the biodiversity-rich climax stage.

Holling's model is a description of how self-organization proceeds in ecosystems in response to external forces. Open systems, such as ecosystems, are constantly balancing these forces (Kay 1994). If the development is focused on one type of structure, the system becomes overextended and brittle. On the other hand, if the organization is not developed enough to take maximum advantage of the available resources, then a better adapted organized structure will emerge to regulate the system. This is in contrast to the view that ecosystems are maximizing or minimizing some objectifiable quantity.

Figure 4.4. Shift to a New Attractor



4.5.2 Opening Presentations

The Working Group considered one specific question: what is the role of the atmosphere in the self-organization of systems? The question was approached from the perspectives of both information and thermodynamics in three opening presentations. Because these presentations provide the basis for the following discussions and ultimate recommendations, they are summarized here.

The Information Role of the Atmosphere in the Self-Organization of Ecosystems - Brad Bass
In the thermodynamic interpretation of Holling's four-box model, the atmosphere transfers energy and nutrients, but the information role of the atmosphere, which has not been considered, may also play an important role in the self-organization of ecosystems. Information is transferred to an ecosystem in the variability of different events. At a particular space-time scale, each meteorological variable can be described by a probability distribution. The ecosystem has adapted to this "signal". Changes in this distribution or the variability of events is important in triggering abrupt changes such as fire or pest outbreaks, but they are also important as the ecosystem begins to reorganize. At this stage, a significant shift in the variability in important meteorological inputs such as temperature and precipitation may represent a strong enough gradient to shift the system to a new attractor, e.g., from tundra to forest.

Conceiving of atmospheric information in this manner has two advantages. First, the probability distributions can be described with information statistics, allowing us to take advantage of information theory to identify possible future states of the ecosystem.[16] Second, the probability distributions can be made conditional on larger-scale atmospheric variables, and these can be used as indicators of atmospheric, and perhaps ecosystem change (Bárdossy and Caspary, 1990). One such application of this idea is "downscaling" which is an approach to linking large-scale climate model output with surface weather at the regional or local scale (Bass and Brook, 1997).

Abrupt changes in global weather and temperature patterns have been found in historical data sets and indeed in paleoclimatological records. These are undoubtedly associated with abrupt changes in the atmospheric general circulation, and it is possible that such discontinuities could shift ecosystems to new attractors, and that they could be studied by classifying general circulation patterns and examining changes in them. Circulation patterns (CPs) can also be classified from the output of climate models, hence a link is provided with climate change scenarios. Objections were raised in the WG as to the robustness of the empirical relationships between CPs and local weather under climate change. This objection is relevant when 2 x CO_2 scenario output is classified into circulation patterns and used to create high resolution data sets. However, if these patterns are used only as an indicator, then even if these relationships are not robust, they can be adjusted as new observations become available.

The Information Function of Biodiversity - Nina-Marie Lister
Within ecology, several types of quantifiable information measures have been proposed: genetic information, a Shannon-Weaver index tied to the number of individuals per species, and an extension of the Shannon-Weaver index to the connectedness of food webs. These measures are problematic, given that within a cell there are four different kinds of information, and their interactions are not fully understood (Lynn Margulis, pers. comm. to Henry Regier). Nevertheless, information is present and plays an important role in an ecosystem in that it enables rapid adaptation, but also constrains the number of possibilities to those that have the greatest chance of success (Schneider and Kay 1994).

The traditional definition of biodiversity refers to the uniqueness and variety of all life, with particular foci on genes, species and landscapes (or ecosystems). Biodiversity should also be considered as having an *information function* which is system-wide, occurring at all levels of the ecological hierarchy, including human culture. As information, biodiversity operates at each phase of the Holling 4-box model. Following episodes of sudden change or "creative destruction",

[16] Schneider and Kay (1994) suggested a similar concept although not in the context of atmospheric change.

biodiversity has a critical function: to facilitate ecosystem reorganisation and regeneration. Thus, in the information context, biodiversity acts as a fail-safe mechanism, ensuring the capacity of an ecosystem to regenerate through self-organisation.

The vast majority of biodiversity research and conservation effort is focused at the species level for the simple reason that it is the least complex and most tangible level of the ecological hierarchy. However, we run a potentially serious risk of weakening system resilience and ultimately compromising ecosystem regeneration and future function if we limit our efforts to only one scale. The information component of biodiversity may be particularly useful as a heuristic for conservation policy/planning and management, in that it facilitates a broader perspective of ecosystem dynamics and development. As such, biodiversity may be considered as an "investment" for both the maintenance of ecosystem function as well as for future regeneration and function. Thus, biodiversity as information provides perhaps the strongest support for the precautionary principle in conservation policy.

As an ecosystem reorganizes or regenerates under new climatic and air quality regimes, it is likely that, even though ecosystem functions are maintained, some species will no longer be able to survive. In these instances, policy directed towards preservation of these species is a value judgement. While this policy may not be valid from the perspective of applied science, it is quite acceptable within the context of *post-normal science*, i.e., science where uncertainties are acknowledged and managed, values are made explicit, and a plurality of perspectives is recognized (Funtowicz and Ravetz, 1993). This new view of science is different from "normal" or applied science, where uncertainties can be controlled or ignored, values are not called into question, and disciplinary assumptions remain hidden. For many environmental policy decisions, the uncertainties are high and the urgency of the decision, or the consequences of being wrong, are considerable. Normal science cannot provide certainty, conflicting perspectives cannot be put aside, and important foundational questions cannot be ignored (Funtowiz and Ravetz, 1993). This view recognizes that the scientific questions and descriptions are only one input into policy. The scientific peer review process is expanded to consider the quality of the data and the interests of stakeholders.

The subdisciplines of experimental design and biometrics are tools available within the context of applied science to deal with uncertainty. Funtowicz and Ravetz (1993) propose a continuum, based on increasing uncertainty and urgency, beginning with "applied science", following the cantons of hypothesis testing and accepted protocols, moving to "consultancy", such as a medical diagnosis, and finally into the arena of post-normal science. Objections were raised by the WG to the term *post-normal science* for what essentially may be called democracy, and that "science", as a way of looking at the world, was being given too much credibility when extended into this area. Although this was not fully resolved, it was pointed out that post-normal science is not just confined to political activity. It does not necessarily eliminate applied scientific work, but stresses the acceptance of uncertainty and delineates a new role for science, that of illuminating the consequences or trade-offs of different actions.

Self-Organization and Spatio-Temporal Patterns in Ecosystems - Jae S. Choi

Patterns of size and abundance exist at many important scales: globally, regionally (landscape), and even at the population level. In numerous studies, this pattern is a log-linear relationship between size and abundance with scaling exponents near -1. It is possible to use this recurrent pattern to estimate the amount of heat leaked from the biotic system. Estimates based upon allometric physiological relationships indicate that systems dominated by rapidly growing organisms (the exploitation function in Holling's four-box model) are *leaky*, which is indicated by much higher rates of energy dissipation or entropy production rates (total and mass specific). Using a biogeographical and experimental approach, it was also demonstrated that body size decreases with increases in temperature. This pattern was demonstrated to exist across many different taxonomic and geographic scales. Most of the data, in the presentation, were collected on poikilotherms (cold blooded). Amongst homeotherms (warm blooded), this pattern is known as Bergmann's rule and is clearly an important and perhaps analogous empirical pattern. There are many potential factors that are at play in regulating this empirical pattern. The most proximate (physiological) explanation is due to the elevated rates of metabolic costs due to a higher temperature environment.

However, fluctuations across many different spatio-temporal scales will influence the form of the size-abundance relationship. Therefore, the return to a semi-log-linear state may be seen as a relation of fluctuations, as termed by Prigogine. The stability of this log-linear state was demonstrated to be related to the stability condition of the minimum dissipation principle of Prigogine (1978). Further, it was hypothesised that the log-linear relationship between size and abundance is indicative of a spatio-temporal fractal pattern, named "self-organised criticality" by Bak et al (1989). Thus, the stability of this very common empirical pattern of non-linear dissipative systems is due to the very same stability condition of Prigogine (1978). Further, the dynamic equilibrium between fluctuations and the approach to the log-linear state is analogous to the concept of ecological succession!

When perturbations are extremely strong, the biotic system enters an extremely non-linear region of dynamics. The implications of this effect are currently being worked out, especially in terms of ecosystem integrity. This may also provide another explanation of why we find evidence of Holling's four-box model. It may be acting as a global optimization procedure to adapt to a variable environment.

Objections were raised by the WG to a thermodynamic explanation for the patterns that were presented relating body size to temperature. A simpler explanation suggests that natural selection selects for larger body size in a colder climate because body volume increases faster than body surface area. Heat retention is proportional to the ratio of body volume to surface area, so a larger body size allows greater heat retention. This is naturally selected for because the capacity for heat retention is required for survival in colder climates. In a recent paper (Fleming and Volney 1995), it is pointed out that the spruce budworm (a poikilotherm) makes a trade-off in allocating the biomass it produces for egg-laying. In northern climates it tends to lay fewer but larger eggs, but in the south it lays more eggs, they are smaller and fecundity is 67% greater. The northern strategy is appropriate for the colder winters, the larger body size providing a greater chance of survival at a cost of reduced reproductivity. It is important to note however, that Choi's presentation focused on the stability of what appears to be a self-organized pattern at the scale of the community.

Discussion

A consensus emerged in the following discussion that atmospheric change would likely alter environments in ways that would endanger some species, but not necessarily affect ecosystem integrity. This is a systems view, intervention to protect a particular species being a technical or engineering view. Protecting ecosystem integrity in the event of atmospheric change does not ensure the protection of all of the existing species. Could the protection of current biodiversity endanger the ability of the ecosystem to adapt to a changing atmosphere?[17] For example, a strategy of protection would emphasize the conservation function in Holling's model, thereby increasing the brittleness of the system, and the amount of fuel that could be consumed by a fire or a pest. In this case, the creative destruction could be less creative" and more "destructive", perhaps flipping the

[17] The group only considered the impact on biodiversity due to atmospheric change, and did not consider other shorter-term threats such as habitat destruction.

system to a new attractor.[18]

Two of the atmospheric issues. climate change and increasing UV-B radiation, are global in scale. However, a shift in climate or UV-B will impact upon particular species in different ways across Canada. A species that cannot survive in one region may be able to survive in another, or perhaps in another country. Some of the affected species may be able to migrate to regions outside of Canada. So it is necessary to plan ahead, developing migration corridors and flyway staging grounds while at the same time recognizing the possibility of undesirable invasive species moving in from other regions. (See recommendation 2 in Section 4.5.4).

The group found it difficult to provide a scientific basis for the protection of specific species, but realised that such recommendations could emerge due to stakeholder values and desires. The policy boundary between these two extremes is probably not distinct. In addition, biodiversity policy can also be formulated at different spatial scales: from the gene, through the population of individual species, and up to the level of the landscape. The Canadian Biodiversity Strategy has identified three such scales. The choice of one scale implies trade-offs. Both of the policy and the scale axes are combined to illustrate the policy continuum between species protection and ecosystem integrity (Figure 4.5.).

Figure 4.5. Policy Continuum for Protection of Biodiversity under Atmospheric Change.

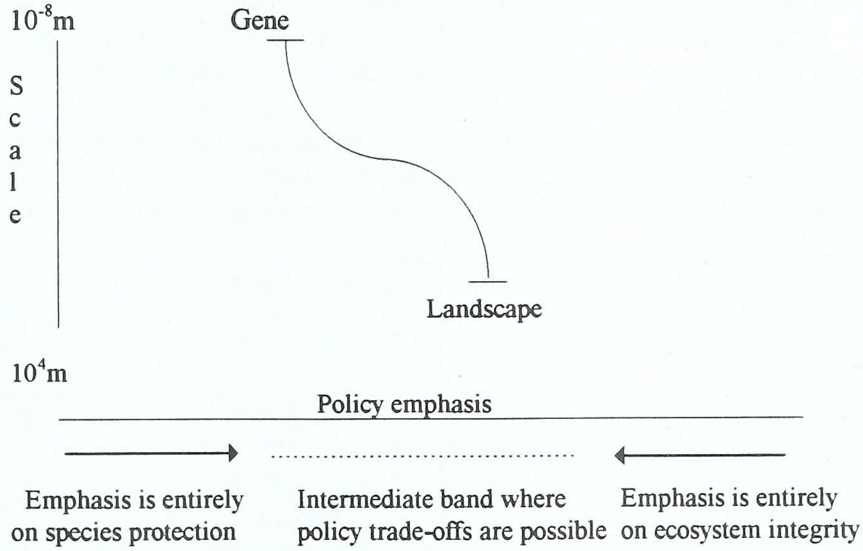


Figure 4.5. illustrates that as policy moves from either extreme towards the middle, a certain amount of ecosystem integrity will be traded off for a certain amount of species protection. The boundary between the two is fuzzy, and in this window, differences in policy may simply be a matter of emphasis. These trade-offs will be manifested differently at different scales ranging from gene to landscape. At the level of the gene, the technical view is one of genetic manipulation on an individual species, and the systems view is to preserve the genetic information that will maintain the self-organizing capability of the ecosystem. At the landscape scale, the technical view is to try and

[18] As this example indicates, the meaning of *integrity* is still somewhat ambiguous. If, in adapting to atmospheric change, the self-organizing processes result in a different type of ecosystem, this new system may still be healthy, able to cope with stress, and able to self-organize. In other words, defining and protecting integrity does not eliminate values and desires from the policy realm. The major difference between protecting ecosystem integrity and protecting specific species is the approach to management. Protecting ecosystem integrity limits the degree of intervention, primarily to the boundary between human and ecological activity.

manage the ecosystem. The system view is to allow the ecosystem to adapt while managing the boundary between human and ecological activity.[19]

The development and evaluation of policies, especially those that may trade-off species protection and ecosystem integrity, require indicators of atmospheric change and biodiversity[20]. The WG identified three promising indicators. (1) Bass proposed that sudden changes in the frequency of different general circulation patterns could be used as an indicator of atmospheric flips. (2) An indicator of species richness as related to changes in upward long-wave radiation, see Currie (1991), Luvall and Holbo (1989) and Schneider and Kay (1994)[21]. (3) Threshold identification: It was suggested that the self-organizing behaviour of biota provides the capacity for ecosystems to rapidly adapt when some critical threshold is reached. The resultant changes may comprise a recognizable indicator of atmospheric change. Three examples were offered: (1) cold-water adapted fish living in an environment that is close enough to their thermal tolerance that a change in ½°C could be significant; (2) insects; Fleming and Tatchell (1994) examined aphid flight phenology at several sites in the UK, and their results suggest that it may be an indicator of climate change; and (3) a local atmospheric indicator based on the location of the Arctic front near Churchill, Manitoba, which can be used to predict the relative warmth of the summer (Scott, 1990). Hansell (paper presented at this Workshop) provided several examples that suggest that summer warmth may be a predictor of the behaviour of certain species.

The Environmental Monitoring and Assessment Network (EMAN) already provides the infrastructure for assessing the impacts of these atmospheric stresses at specific locations. The EMAN programme should be extended to include investigating the potential impacts of atmospheric change on biodiversity (McNeely 1990) and developing additional local indicators. The framework for such an extension is already in place in the Multi-Issue Assessment of Atmospheric Change and in the Canadian Biodiversity Programme. The atmospheric change issues can be viewed within the following matrix. (See recommendation 4 in Section 4.5.4.)

Biodiversity/ Atmosphere	Climate Change	UV Radiation	Acid Rain	HAPs	Smog	Suspended Particulates
Genetic						
Population						
Landscape						
Spatial Scale	Global		Regional		Local	

The first step is to build on the results of Working Group III and identify those atmospheric stresses that are relevant to the different EMAN sites. The global issues affect every part of the country, while all six issues effect some locations, e.g., Toronto. At other locations, a different mix of issues may be important for biodiversity. The next step is to promote proposals to use EMAN sites to assess the impact of atmospheric change on biodiversity. The hypotheses should specifically be formulated in a manner that address non-linearities, critical thresholds, and some of the questions of self-organization identified above.

[19] This point is also echoed in Kay (1994).
[20] Bob Slater challenged the workshop to make recommendations as to specific indicators.
[21] Schneider and Kay (1994) proposed that ecosystems develop additional structure to degrade energy gradients more effectively. The authors expected that mature systems use, or degrade, more of the incoming energy, and thus are less leaky than more primitive ecosystems. Mature systems should have a colder black body or radiative temperature.

4.5.4. Recommendations

1. When studying the effects of atmospheric change on biodiversity, more attention should be given to the concepts of ecosystem integrity, self-organizing non-equilibrium systems, the ecosystem approach and surprise. These concepts altogether provide a useful framework for understanding the effects of atmospheric change on biodiversity, and thus provide a valuable policy tool.

2. Atmospheric and biodiversity changes are no respectors of jurisdictional boundaries. The Canadian biodiversity science agenda should include studies of potential changes in both national and international species migrations along corridors, flyways and staging grounds for migrating species in an era of a warmer climate. This should include studies of potential corridors for the invasion of undesirable alien species, and the design of early warning monitoring systems. The guidelines for preserving/establishing corridors will need to be adjusted regionally, recognizing that parts of British Columbia and the Yukon are "topographically challenged"[22] .

3. More emphasis should be given to the fact that biodiversity policy will often involve trade-offs between protection of species and of ecosystem integrity. [The role of science is to illuminate these trade-offs and consequences.]

4. The development and evaluation of biodiversity policies, especially those that may trade-off species protection and ecosystem integrity, require indicators of both atmospheric and biodiversity changes. Three potential indicators that should be explored are:

   1. Long-term changes in the frequencies of atmospheric general circulation patterns;
   2. Changes in species richness as related to changes in upward long-wave radiation;
   3. Sudden changes in ecosystem behaviour once a threshold in atmospheric change is exceeded.

The EMAN network is recommended for testing these and other indicators, using localized atmospheric conditions and localized knowledge.

4.5.5. List of Presentations to the Working Group

1. Brad Bass, "The Information Role of the Atmosphere in the Self-Organization of Ecosystems".
2. Nina-Marie Lister, "The Information Function of Biodiversity".
3. Jae S. Choi, "Self-Organization and Spatio-Temporal Patterns in Ecosystems".

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[22] This term was suggested by Eric Taylor in Working Group V.

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Chapter 5: Where Do We Go From Here? Sound Advice from Seven Wise Practitioners

5.1. Preamble

The Workshop concluded with a Panel Discussion chaired by Tom Brydges, with Panelists Alex Alusa, Allan Baker, Jeff McNeely, Jeffrey Watson, Bruce Wiersma and Richard Hebda. These "wise practitioners" were subsequently invited to write down the essence of their remarks. Naturally, there was some duplication of good ideas amongst the Panelists and with some of the points in the five Rapporteur Reports. After some editing, the main new ideas that came out of the discussion follows.

5.2. Comments by Alex Alusa, UNEP

- Three global environmental issues are strongly inter-related: biodiversity, climate change and stratospheric ozone depletion. Every effort should be made to establish, insofar as possible, mutually supportive science agendas with respect to these three issues in terms of monitoring, research and assessment programmes, and of policy formulation.
- UNEP should continue to play an important coordinating role in the refinement of international and national science agendas related to the three issues.

5.3. Comments by Allan Baker, Royal Ontario Museum

- We are witnessing one of the greatest losses of biodiversity our planet has ever suffered. Within the lifetimes of our children, if current rates of loss continue, between 30 and 90% of all life forms will become extinct. This crisis is almost entirely induced by humans, and it can be arrested if drastic action is taken.
- Atmospheric change will accelerate loss of species, and will itself be accelerated by the destruction of habitats and ecosystems via feedback processes.
- One of the most pressing problems is that we do not have even an approximate estimate of the world's total biodiversity, with guestimates ranging from 5-30 million species. This problem also exists in Canada, and a massive effort will be required to meet our obligations as a signatory to the International Biodiversity Convention. Clearly, we need to train a new generation of systematists to carry out this Herculean task, we must network our agencies much more effectively, and we must direct appropriate resources to them.
- Biodiversity is an economic asset, and needs to be thought of as such. Apart from the multi-billion dollar annual economic input of biodiversity in agriculture, fisheries, and forestry, natural products as yet undiscovered in plants and animals are of vast economic potential.
- We need to develop an international code of bioethics in which we give equal respect to all forms of life on our planet, and to instill this in our children. Biodiversity is crucial for human survival, and in one sense we are fortunate to be alive at a time when we scientists can make a difference.

5.4. Comments by Jeff McNeely, IUCN

- More emphasis should be placed on linking conservation, protected areas, bioregions (the landscapes surrounding protected areas) and climate change. In particular:

    1. One of the objectives of the Climate Change Convention should be the determination of those species and ecosystems in protected areas (and other biodiversity "hot spots") that would be particularly stressed by climate change.

2. In the long run, protected areas can be expected to support only those species that can survive in a space smaller than the protected area (see Figure 4.1). Thus, care should be taken to ensure that the surrounding bioregion is not subjected to ecologically incompatible land uses.

3. A protected area should be the core of a much larger bioregion research program, the broad objective being to maintain biological diversity in both the protected area and the surrounding bioregion in an era of climate change. (A drainage basin is a natural bioregion for assessments of the effects of climate change on land and water systems, and thus for biodiversity assessments.)

4. Close cooperation is required among the diverse disciplines and groups interested in biodiversity, in assessments of the effects of climate change on protected areas and bioregions.

- The IUCN Commission on National Parks and Protected Areas could provide valuable advice to national bodies on the management of protected areas and bioregions.

5.5. Comments by Jeffrey Watson, Canadian Global Change Program

- The Canadian Global Change Program (of the Royal Society of Canada) has as one of its major foci, global change and biodiversity. The CGCP is committed to working in partnership with like-minded organizations such as the sponsors of this Workshop.
- The Report of the Workshop, and the Canadian science agenda that will follow, should be disseminated widely for comment, so that consensus on content and priorities in the science agenda can be achieved. The CGCP would be pleased, in its capacity as an honest broker (being an independent and impartial body) to promote the science agenda to funders in government, the private sector and the granting councils via specific research proposals.
- The need to establish research priorities is of great importance. Perhaps the first step is to improve methods for priority-setting.

5.6. Comments by Bruce Wiersma, University of Maine

- Major constituency groups should be involved in the design and execution of research and monitoring programs relating to the effects of atmospheric change on biodiversity. The constituencies that should be included are the relevant scientific societies, environmental groups, and industrial bodies, as well as federal and provincial agencies. There are two reasons why this is important:

  (1) The input of these groups will be invaluable in the design and implementation of the program;
  (2) Atmospheric change/biodiversity studies will need to run for decades, and the existence of involved and supportive constituency groups will be a significant factor in maintaining the political support needed to assure continuing funding over the long term.

5.7. Comments by Richard Hebda, Royal British Columbia Museum

- A conclusion of this Workshop must be that the evidence is no longer ambiguous: atmospheric change is a reality, and it has already had some effects on the biosphere and biodiversity. In coming decades, these effects will become much greater.
- Insufficient emphasis is given to field work. IT'S TIME FOR BOOTS, NOT SUITS!
- A major research task is to identify migration corridors and ecotones (areas of sharp ecological gradients), particularly those due to sharp climatic gradients. Emphasis should be on both whole ecosystems and on populations of individual species.

- Non-specialists, e.g., young people and First Nations members, need to be encouraged. This will provide an informed committed group for the future. Some training will be needed, and this will require the development of training manuals, CD ROM's, etc.
- There is need for a media contact in each region, somebody who can coordinate new information on atmospheric change and biodiversity as it becomes available.

5.8. Comments by Tom Brydges, Canadian Ecological Monitoring Coordinating Office (EMCO)

- Environmental issues tend to arise as a result of some particularly dramatic observation. For example, algae scums in Lakes Erie and Ontario in the 1960's triggered the eutrophication issue, acid lakes in Muskoka fanned public concerns for acid rain in the 1970s, the hot dry summer of 1988 triggered public concern about the climate warming issue and the NASA prediction of severe stratospheric ozone depletion in 1992 gave rise to public concern about skin cancer.
- Following the initial pulse of public interest, scientists must work in the scientific trenches over the long haul. For example, Great Lakes productivity and eutrophication issues continue to this day. Recent reports from Quebec and elsewhere have drawn attention to long-term cumulative affects of acid rain on forests and soils. Recent reports have shown that changes in lake water chemistry can increase their vulnerability to even ambient levels of UV-B, and climate change is now focusing on extreme events, such as the hottest, driest, and even the coldest conditions.
- Biodiversity has followed the same pattern with headlines coming from the possible extinction of large mammals, such as panda bears and tigers. However, maintaining public interest and policy activities over the long time-frame required to deal with biodiversity is a major challenge for the scientific community. The long-term subtle, and inherently more complicated changes are difficult for the general public to understand, but such awareness is critical if the necessary public support is to be maintained.
- The Ecological Monitoring and Assessment Network (EMAN), is one vehicle available to mobilize and organize the scientific machinery, to monitor, to assess data and to report regularly to the general public. The National Science Meeting held every January is a forum for presenting information. At the 1996 meeting, there were papers on the relationship between acid rain and forest health, changes in lake chemistry and their primary productivity, and biodiversity changes in the Mixedwood Plain ecozone. It is our intention to increase this scientific assessment activity at our next Science Meeting in Saskatoon in January 1997.

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Chapter 6: THE ELEMENTS OF A SCIENCE AGENDA IN THE AREA OF ATMOSPHERIC/BIODIVERSITY CHANGES IN CANADA[23]

6.1. Introduction

Scientists widely believe that unprecedented atmospheric changes will take place in the next century. What research should be undertaken to determine how these changes will affect biodiversity? What monitoring systems should be established to test hypotheses on atmospheric/biodiversity changes and to provide early warning of impending changes? And what policies should be adopted by society to counter the harmful effects on the biosphere and human welfare that might ensue? The main objective of this Workshop was to develop a Canadian science agenda to answer these questions.

In this concluding chapter, a broad outline is proposed for a science agenda (research, monitoring, policy) in the area of atmospheric/biodiversity change, taking into account the large number of recommendations made by the five Working Groups (Chapter 4), the comments of the seven panellists (Chapter 5) and some suggestions made subsequently by members of the Workshop Steering Committee.

Of course, some of the proposals made by the Working Groups and panellists are tentative, requiring further discussion. In fact, this Chapter might usefully become a Discussion Paper for a follow-up meeting on the same topic by a small group of practitioners and policy analysts representing the principal stakeholders insofar as possible.

6.2. General Principles

1. In order to advance knowledge on the effects of atmospheric change on biodiversity, field studies and model development will be essential. The elaboration of a coherent research program is greatly complicated by the fact that some of the atmospheric changes are already taking place while others are not likely to become significant for at least 50 years. In this latter case (e.g., the various manifestations of climate change), four major problems arise when trying to establish atmospheric/ecological relations:

> (1) Because the six air issues are strongly inter-related, a change in one of the issue indicators may affect the rate of change or even the sign of the change) in indicators of some of the other issues.
>
> (2) Apart from laboratory experiments in manipulated environments, the only possible ways to explore the future is through simulation models (based on socio-economic scenarios), which may not include the full range of conditions expected in the 21st century.
>
> (3) Populations of some species are subject to natural boom-and-bust cycles (the lemming and the spruce budworm, for example) and losses (due to forest fires, droughts, floods, etc.). It is therefore difficult to distinguish natural from human-induced changes.
>
> (4) The life cycles of many ecosystems are much longer than those of the lifetime careers the scientists who study them.

2. The EMAN (Ecological Monitoring and Assessment Network) program is endorsed as the foundation for field studies on biodiversity and atmospheric change in Canada. Scientists interested in these kinds of studies should make known their special needs to EMAN.

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[23] *Contributed by R.E. Munn, L. Cartmale and A. Maarouf*

3. Encouragement should be given to ecological/biodiversity model builders, through financial assistance for: (1) the collection of appropriate field data for model performance testing; (2) salaries of graduate students; and (3) travel to national and regional meetings dealing with the effects of atmospheric change on biodiversity.

4. Considerable attention should be devoted to research frameworks, methodologies and protocols for studying the effects of atmospheric change on biodiversity. In particular, studies within the context of self-organizing ecosystems should be given more emphasis. The ideas of ecosystem integrity, self-organizing non-equilibrium systems, the ecosystem approach and uncertainty altogether provide a useful new framework for understanding the effects of atmospheric change on biodiversity.

5. Closer connections should be established between the community studying atmospheric change and the community studying biodiversity. This could be fostered through federal and provincial agencies, the relevant scientific societies, NGOs and industrial associations. Interdisciplinary collaboration should also be expanded to include engineering, the health sciences and the main social sciences.

6. Linkages should be established with U.S., Inter-American and global bodies (e.g., UNEP, IUCN) with an interest in the effects of atmospheric change on biodiversity.

6.3. Specific Research and Monitoring Programs

6.3.1. Monitoring of biodiversity and atmospheric change

1. There is need to establish a national set of indicators of biodiversity and atmospheric change. The set may, of course, be rather large in view of the various ecological and atmospheric scales involved, and the huge numbers of species that altogether comprise the Canadian biodiversity assemblage.

- Umbrella species that integrate complex information within communities
- Functional indicators, e.g., decomposers, nitrogen fixers
- Keystone species, e.g., large mammals, the arctic char
- Species that are widely distributed across Canada, so that comparisons can be undertaken across the EMAN network
- Phenological indicators, e.g., dates of blossoming, break-up of river ice
- Composite indicators of ecological integrity
- Proxy indicators, e.g., tree rings, sediments and other paleo indicators
- Downscaling (for atmospheric change)
- Upward long-wave radiation from terrestrial ecosystems (for biodiversity)
- Identification of sudden and generally surprising changes in ecosystem behaviour (seeking to correlate these changes with critical thresholds in atmospheric change)
- Traditional local knowledge of both atmospheric and biodiversity changes in former times.

Because biodiversity may change also for reasons not related to atmospheric change, a suite of supporting indicators ought to be monitored, including degradation of habitat and staging grounds (for birds), cut-line and road construction, predator-prey interactions, pest infestations, and water quality (in the case of freshwater and marine ecosystems).

2. Relative changes in biodiversity should be assessed at co-located sites where the behaviour of unmanaged versus managed ecosystems can be monitored and modelled.

6.3.2. Research

1. Research should be carried out iteratively with monitoring programs, the main goal being to develop improved prediction models of relationships between atmospheric change and losses of biodiversity and degradation of ecosystem functions.

2. To assist social scientists in participating more meaningfully in atmospheric/biodiversity change studies, an inventory should be prepared of potential atmospheric scenarios possible in the next 50 years, together with the likely consequences for biodiversity, and the socio-economic implications.

3. The biodiversity of EMAN sites should be evaluated in terms of sensitivity to changes in the six atmospheric stressors over the next fifty years.

4. Another of the objectives of the research program should be to provide practical information to policy makers and the public on such questions as:

(a) What is the natural biodiversity potential of each part of Canada?
(b) If a region such as Southern Ontario is presently operating below its biodiversity potential, given the additional stresses expected due to atmospheric change, what might be the long-term consequences for ecosystem functioning, and what advice on remediation can scientists give to policy-makers?

6.3.3. Landscape-level studies

1. More emphasis should be given to landscape-scale studies of the effects of atmospheric change on biodiversity.

2. Satellite detection of biodiversity changes should be given increased priority. Satellites can provide long-term ecological data on a scale of 1km x 1km, which is invaluable for long-term studies of fragmentation, loss of corridors, movements of ecotones and degradation of habitats. The Canada Centre for Remote Sensing should be encouraged to work with users in providing such information. Emphasis should also be placed on ground-truth assessments of the satellite data, using EMAN stations.

3. In addition to intensive studies at EMAN stations, extensive biodiversity transects should be undertaken across gradients of climate, chemical characteristics of the atmosphere and physiographic properties of the underlying surface. These transects should be repeated periodically in order to obtain information on annual cycles and long-term trends. They should include not only transects across tree lines and inland from water bodies but also across urban-suburban-rural configurations.

4. On a larger scale, the Canadian biodiversity/atmospheric science agenda should include studies of potential changes in both national and international species migrations along corridors, flyways and staging grounds in an era of warmer climate when wetlands may dry up, forest ecosystems may begin to shift northward, and large areas of permafrost may disappear. These studies should include investigations of potential pathways for the invasion of undesirable alien species, and the design of early warning monitoring systems.

6.3.4. Transects across gradients of climate, chemical characteristics and ecosystem properties

1. In addition to intensive studies at EMAN stations, extensive transects should be undertaken across gradients of climate, chemical characteristics of the atmosphere and ecosystem properties. These transects should be repeated periodically in order to obtain information on annual cycles and long-term trends. They should include not only cross-sections at right angles to tree lines and water bodies but also transects across urban-suburban-rural configurations.

2. On a larger scale, the Canadian biodiversity/atmospheric science agenda should include studies of potential changes in both national and international species migrations along corridors, flyways and staging grounds in an era of a warmer climate when wetlands may dry up, forest ecosystems may begin to shift northward, and large areas of permafrost may disappear. These studies should include investigations of potential pathways for the invasion of undesirable alien species, and the design of early warning monitoring systems.

6.3.5. Identifying and cataloguing biomes and sectors most at risk

1. Special emphasis should be given to biodiversity "hotspots" in Canada, i.e., biomes and sectors most at risk from atmospheric change. Examples include the Arctic where UV-B has increased, and relict terrestrial and freshwater habitats in the Mixedwood Plains Ecozone of Southern Ontario where the combined actions of atmospheric change and land-use development make them particularly vulnerable.

2. Special attention should also be given to protected areas and surrounding bioregions. An effort should be made to determine those species and ecosystems that would be particularly stressed by climate change.

6.3.6. Priority setting

There is an urgent need to establish research priorities with respect to studies of the effects of atmospheric change on biodiversity. One tool that would assist in this task is that of multi-issue science assessments (Munn, 1995).

6.4. Complementary Socio-Economic Studies

1. The various options for responding to the effects of atmospheric change on biodiversity should be laid out in an informed and publicly accessible fashion. The information provided should include for each alternative: the reasoning; reasonable cost estimates and potential benefits; the ethical underpinning; and the expected outcomes. The protection of ecosystems and ecosystem integrity is perhaps the most cost-effective way to protect biodiversity, but this will often involve trade-offs between protection of individual species and ecosystem integrity. [The role of science is to illuminate these trade-offs and consequences.]

2. A small group of social scientists (including Ian Burton and Peter Timmerman) should be commissioned to write a paper on the subject, “Elements of a socio-economic research strategy for responding to changes in the atmosphere and biodiversity”. [A framework for this paper was given in Section 4.4.1 of this report].

3. A careful examination is required of what we value/what is valuable in the atmospheric change/biodiversity debate.

4. A broader definition/mandate for managing biodiversity should be developed, with a move away from an overly single-species preservationist view.

5. Departmental guidelines on sustainability should be expanded to include guidelines on biodiversity and atmospheric change.

6. Natural scientists should work with social scientists to connect ecological adaptability/resilience/productivity to equivalent socio-economic conditions.

7. Efforts should be made to improve the response capabilities of the relevant bureaucratic and political systems with divided jurisdictions and overlapping boundaries, which limit capacities for dealing with the atmospheric change/biodiversity issue.

6.5. The Role of Industrial Associations

Industrial associations have an important role to play in the atmospheric change/biodiversity change issue. In particular,

1. Industrial associations should support research seeking to quantify the socio-economic benefits to be derived from biodiversity conservation and the further development of bioremediation technology in an era of atmospheric change.

2. Industrial associations should support Research and Development designed to illuminate the problem of how to include biodiversity considerations in environmental assessments and cumulative environmental assessments.

3. All relevant partners including industrial associations should be invited to participate in a Science and Policy Forum on the Effects of Atmospheric change on Biodiversity Loss and Degradation of Ecosystem Functions.

6.6. Concluding Remarks

Sections 6.2-6.5 outline the elements of a science agenda in the area of atmospheric/biodiversity change in Canada. It is recommended that this material be widely circulated for comment, subsequent modification and final adoption.

The 1995 Rio UNCED Conference (United Nations Conference on Environment and Development) gave high priority to a number of inter-related global issues, including climate change, stratospheric ozone depletion, acid rain, and biodiversity, which could become severe threats to the biosphere and society before the end of the 21st century. This Workshop dealt with the effects of atmospheric change on biodiversity, which is a major component of the UN Agenda 21 program approved at Rio. The emphasis has been on a Canadian science agenda but many of the recommendations are relevant in other countries, and - on a smaller scale - to Canadian provinces and counties.

REFERENCE

Munn, R.E. (ed.) (1995) *Atmospheric Change in Canada: Assessing the Whole as Well as the Parts, Summary of a Workshop*, Institute for Environmental Studies, University of Toronto, Toronto, 36pp.

APPENDICES

APPENDIX A WORKSHOP PROGRAM

Atmospheric Environment Service, Environment Canada, 4905 Dufferin St., Downsview, ON

Monday, February 26, 1996

1:30 p.m. **Plenary Session** (Chair, *R. White*, Director, IES)

Opening Address: *R. Slater*, Assistant Deputy Minister, Environmental Conservation Service

"Why Biodiversity? Adapting to Change", *J. McNeely*, IUCN

"Atmospheric Change and Biological Diversity: UNEP's Role in Developing the Linkages", *A. Alusa*, Atmosphere Unit, UNEP, Nairobi

"Linking Biodiversity and Ecosystem Functioning: Insights from Grasslands", *D. Wedin*, University of Toronto (U of T)

"Atmospheric Change: Biological Link and Role of the Atmosphere", *D. MacIver*, Atmospheric Environment Service (AES)

8:00 p.m. **Dinner Address**, *K. Hare*, Department of Geography, U of T

Tuesday, February 27

9:15 a.m. **Plenary Session,** Chair: *G. Thompson*, Environment Canada

"Impacts of Acid Rain on Floral Change in Europe and North America", *T. Hutchinson*, Trent University

"Atmospheric Change and Ecosystem Protection: A National Parks Perspective", *D. Welch*, Parks Canada

"The Effects of Global Climate Change on Landscape Diversity: an Example in Ontario Forests", *I. Thompson*/M. Flannigan/M.Wotton, Natural Resources Canada/R. Suffling, University of Waterloos

"The Social and Economic Implications of Changes in Biodiversity" *P. Timmerman*, IFIAS and IES, I. Burton, AES and IES

1:15 p.m. **Working Group Sessions**

Wednesday, February 28

9:15 a.m. **Sectoral/Regional Papers,** Chair: *G. Holroyd*, Canadian Wildlife Service

"Atmospheric Change and Forest Biodiversity in Canada", *R. Hebda*, Royal British Columbia Museum

"Atmospheric Change and Biodiversity: Impacts of Wildlife in Atlantic Canada", *R. Elliot*, Canadian Wildlife Service

1:15 p.m **Working Groups**

Thursday, February 29

9:15 a.m. **Plenary Session - Reports of Rapporteurs** Chair: *D. McKay*, AES

10:30 a.m. **Panel Discussion** - "Where Do We Go From Here?"

Chair: *T. Brydges*, Ecological Monitoring Coordinating Office

Panelists: *A. Alusa*, UNEP; *A. Baker*, Royal Ontario Museum; *R. Hebda*, Royal British Columbia Museum; *J. McNeely*, IUCN; *J. Watson*, Royal Society of Canada; *B.Wiersma*, University of Maine

12:30 p.m. **Summary:** *I. Burton*

12:45 p.m. **Closing Remarks:** *R.E. Munn*

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