TOWARDS A SET OF BIODIVERSITY INDICATORS FOR CANADIAN FORESTS:

PROCEEDINGS OF A FOREST BIODIVERSITY INDICATORS WORKSHOP

held at

Sault Ste. Marie, Ontario

on

November 29 – December 1, 1993

Editors

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Brendan G. Mackey, and Kathy L. Campbell

Published by
Natural Resources Canada
Canadian Forest Service–Ontario

Sault Ste. Marie, Ontario, 1994

Catalogue No. Fo18-34/1993E
ISBN 0-662-22661-5

Canadian Cataloguing in Publication Data
Proceedings of a Forest Biodiversity Indicators Workshop
(1993: Sault Ste Marie, Ontario)

Towards a set of biodiversity indicators for Canadian forests:
Proceedings of a forest biodiversity indicators workshop.
Sault Ste Marie, Ontario, November 29 – December 1, 1993

Includes bibliographical references.
ISBN 0-662-22661-5
Cat. no. Fo18-34/1993E

1. Forest conservation — Canada — Congresses.
2. Biological diversity — Canada — Congresses.
3. Biological diversity conservation — Canada — Congresses.
I. McKenney, Daniel William.
II. Great Lakes Forestry Centre.
III. Title.
IV. Title: Proceedings of a forest biodiversity indicators workshop,
Sault Ste Marie, Ontario, November 29 – December 1, 1993.

SD118.F67 1994 333.75'16'0971 C94-980372-3

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Acknowledgments

The workshop organizers and proceedings editors were Brendan Mackey (now at the Australian National University), Dan McKenney, Richard Sims, and Kathy Campbell of the Canadian Forest Service (CFS)–Ontario. Jim Farrell, Director, Forestry Development and Liaison, CFS–Ontario, chaired the workshop. Greg Wickware of Geomatics International, Burlington, Ontario, acted as a rapporteur, synthesizing and documenting the workshop. In addition, Michael Soulé assisted the organizers in scoping and guiding the workshop and in preparing the final document. Dr. Soulé is Chair in Environmental Studies at the University of Santa Cruz, California, and the author of numerous papers and editor of several well-known books in the field of conservation biology. Sheila Walsh, CFS–Ontario, was also instrumental in bringing the final document together. The CFS and Environment Canada (State of the Environment Reporting) provided funding. Finally, we would particularly like to thank the workshop participants for their input, candor, comments, opinions, and viewpoints. We hope we have captured some of their important messages and perspectives in these proceedings.

Preface

Michael Soulé

The Canadian Forest Service (CFS) hosted a three-day workshop, November 29 – December 1, 1993, in Sault Ste. Marie, Ontario, to produce a preliminary list of recommended indicators of forest biodiversity. The 1992 National Forest Strategy of the Canadian Council of Forest Ministers calls for the development of such a system of indicators. Monitoring these indicators would form a basis for periodic reporting on the state of forest biodiversity in light of the stated goal of achieving sustainable forest management. There are currently several initiatives to support these efforts, including this workshop.

The workshop featured break-away group discussions on species-based indicators and system-based indicators, although several talks were interspersed to provide perspective and background. Feedback and integration occurred formally during plenary sessions and informally during breaks and meals. Speakers and participants included representatives of federal and provincial agencies, the private sector, and academia. Experts from the United Kingdom, Australia, and the United States were also in attendance.

The need for a system of biodiversity indicators was underscored by reference to the important role of forest products in the national and provincial economies, the likelihood of increasing national and international demand for wood products, trends in extraction technologies, and a potentially conflicting call for overall planning for long-term sustainability.

It was agreed that the problem of achieving a set of national biodiversity indicators is formidable. One reason for this is the inherent complexity of ecosystem/landscape phenomena and their dynamics. Although many experts agree that hierarchical models and attention to scale help us classify and communicate about genes, populations, species, associations, and ecosystems, it was also appreciated that many phenomena transcend spatial boundaries and sometimes confound attempts to categorize and simplify. It was noted that management models such as adaptive management and ecosystem management provide some heuristic assistance but cannot produce specific recommendations for indicators, in part because the local context and nonlinearity of ecological dynamics demand specific as well as general knowledge.

Workshop recommendations were classified into general and specific groups. Among the *general recommendations* were:

- to make more efficient use of existing data, such as the CFS Forest Insect and Disease Survey (FIDS) and provincial data bases and assessment programs;
- to develop a nationwide emphasis on biological surveys and inventories that include accurate georeferencing;
- to intensify and improve coordination of certain types of long-term ecological research and monitoring;
- more emphasis on biodiversity conservation in resource management valuation and plans;
- greater use of digital mapping, spatial referencing of data, automated cartography, and visual output of results; and
- greater emphasis on computer modeling.

It was also concluded that frameworks and objectives for indicators should be clearly articulated.

General recommendations about indicators included the requirements that surveys and monitoring:

- provide better information about the genetic diversity of trees (in Canada, there are numerous widespread and abundant species; consequently, differences between populations are an important issue);
- produce better information on the geographic distributions of species;
- reflect overall system health, viability, and function;
- incorporate the benefits of species- and system-based approaches;
- provide "early warning" services;
- be useful for predicting future trends (e.g., toxic compounds, types and lengths of new roads); and
- use standardized methods.

In addition, indicators should form a comprehensive and integrated system; for example, it would be inefficient and wasteful if some units monitored only insects and others monitored only nutrient dynamics.

Among the *specific indicators* most frequently recommended were *Drivers of Change*; these include measures of fragmentation and disturbance, such as cumulative area logged, access as measured by roads, area burned, conversion of riparian and wetland habitats, pollutants, numbers of exotic species, and harvest levels of fish and wildlife. An important component of this category is *Measures of Stress*; it could include changes in species richness and diversity, increases in pollution-tolerant species, changes in frequencies of abnormalities and asymmetry, frequency and amplitude of insect outbreaks, and pollutants in tissues. A second group of indicators is actual *Measures of Change in Biodiversity Attributes.* These include guilds, taxa, and particular phenomena; a partial list includes carnivores, endangered species, lichens, amphibians, salmonids, migratory birds, nocturnal moths, forest floor beetles, loss of landscape connectivity, water quality and flow, forest regeneration success, and decreases in density of snags and coarse woody debris.

The role of the public and of volunteers in biodiversity conservation was discussed. Examples of public involvement in monitoring from Canada and other countries were mentioned. The view was that there is a crucial role for the public. Well-coordinated involvement in monitoring could be very cost-effective.

Workshop Results

Daniel W. McKenney, Richard A. Sims, Michael E. Soulé, and Brendan G. Mackey

Introduction

Concern over the planet's biodiversity in recent years has resulted in much activity in both science and politics. The essence of the concern revolves around the impact of current economic activity on the planet's life support systems. Biodiversity is an inextricable part of these systems. Although much of the focus of public debate has been on biodiversity loss in the tropics, increasing attention is now being given to temperate, boreal, and other ecological zones. Canada, as a major forest nation and the world's largest exporter of forest products, has a critical role to play in both the science and policy of biodiversity conservation.

In 1992, the Canadian Council of Forest Ministers, in concert with a multitude of partners, produced a National Forest Strategy entitled *Sustainable forestry: a Canadian commitment.* The report contains references and specific commitments to a system for reporting, nationally, on the state of forest biodiversity. This includes development of a system of national indicators to monitor and report regularly on progress in achieving sustainable forest management.

The National Forest Strategy was developed prior to the recent United Nations Conference on Environment and Development (UNCED) and provided a basis for Canada's position on forest-related issues and commitments. A Convention on Biodiversity, which was signed by Canada at UNCED, is intended to promote the conservation of biodiversity and the sustainable use of these resources. Among other obligations, signatories are expected to:

- develop national strategies;
- undertake studies assessing the status of biodiversity and processes impinging on its conservation; and
- collect, assess, and make available relevant and reliable data in a form suitable for decision making at all levels.

Canada is developing a Canadian Biodiversity Strategy that will reflect the measures for conservation and sustainable use of biodiversity contained in the Convention.

Further, the Canadian Forest Service (CFS) issues a national report, tabled each year in Parliament, that provides an account of the condition of forest resources in Canada. This annual report on the state of Canada's forests includes some broad perspectives on biodiversity (Forestry Canada 1993). Environment Canada also reports on other aspects of biodiversity (e.g., Environment Canada 1991a,b).

The goal is relatively clear for forests: we want to have our cake and eat it too. We want to in fact continue to use the forest, we want it to be there for future generations, and we all want to feel good about it.

To help make progress on establishing a set of indicators of biodiversity in the context of Canadian forests and forestry, CFS hosted a three-day workshop, November 29 – December 1, 1993, in Sault Ste. Marie, Ontario. The major objective of the workshop was to recommend a set of biodiversity indicators relevant to Canadian forests.

The workshop format, which included roundtable and break-out group discussions, was designed to provide a forum for open, frank debate about the scientific merit, methodologies, difficulties, caveats, and opportunities for developing an indicator set that could describe and monitor biodiversity. A focus paper entitled "Towards a Set of Biodiversity Indicators for Canadian Forests" was sent to participants prior to the workshop to provide some background and help initiate discussion on some of the major issues in the development of meaningful biodiversity indicators. Several invited speakers also provided context and background to the issues. The 20 participants to the workshop represented a range of expertise, subject matters, geographic conditions, and experiences in biodiversity-related issues. The participant list is provided in Appendix 1.

Following the workshop, the organizers compiled a draft proceedings from notes, some 180+ pages of transcripts, and various other workshop materials (e.g., flipcharts, overheads, handouts) and circulated the draft for comment amongst the participants. The package was then revised for publication. This Workshop Results section contains an overview of biodiversity indicators, a framework for thinking about the problem of developing indicators as conceptualized by the participants, and the workshop recommendations. Sidebars are taken from transcripts of the workshop and are simply intended to reflect the nature of some of the discussions that took place during the workshop.

The remainder of the proceedings contains several papers and synopses of presentations made during the workshop. Mackey, McKenney, and Sims set out an in-depth discussion of many of the issues and problems inherent in developing a comprehensive set of biodiversity indicators. Their overview reinforced the perspective that the development of biodiversity indicators is complex for a variety of reasons, including scale, disturbance regimes, and the influence of the physical environment. Sims and Addison gave an overview of biodiversity and forestry in Canada. They made an often overlooked point that technological change and opportunity will drive forest management practices. Effects on biodiversity should be closely monitored.

One of the things that's probably most bewildering people who approach biodiversity conservation is that there is so much information.

Welsh provided a perspective on conservation biology in Canada. As a practising wildlife ecologist, he brought an important real-world perspective to the issue. Soulé and Kessler provided two provocative views about the way society should be thinking about biodiversity conservation—species- versus system-based approaches. These represent ongoing debates in the field of conservation biology. In the end, it seemed as though there was consensus that a mix of the two philosophies is really required.

The final day of the workshop gave several of the participants an opportunity to present some regional experiences and perspectives in biodiversity conservation. Evelyn Hamilton is a resource ecologist with the Ministry of Forests in British Columbia, Judy Loo is a geneticist with CFS–Maritimes, and Dennis Joyce is a provincial forest geneticist with the Ontario Ministry of Natural Resources.

The appendixes consist of:

- the participant list;
- the workshop agenda; and
- a bibliography of biodiversity-related articles.

Biodiversity indicators—an overview

People want to know how our forests are doing. What are the best indicators? What kinds of indicators are needed? How many are needed? How do we monitor them in order to extract the maximum credible information for the minimum expense?

A forest may harbor hundreds or thousands of species of plants, insects, worms, spiders, mites, fungi, vertebrates, and other taxa, including commercially

No matter what the product is, we always ask these four questions: What is happening out there? Why is it happening? Why is it significant? and What are we doing about it?

important species like spruce and salmon. It may have dozens of easily recognized habitats or ecosystems; its topography may vary. It enfolds untold numbers of physiological, behavioral, ecological, and evolutionary processes.

The forest also provides important services and resources to human beings, not the least of which are fresh water and aquatic recreation. Water quality may be an issue. Some streams may be subject to mine runoff or to sedimentation from roading or logging activities.

All of these entities—species, communities, habitats, services—might reflect how the forest is doing. And if the forest is being harvested by humans, we might even want to know about (monitor) the behavior of these people. What are they taking out, and what are they leaving behind? What are the immediate and long-term consequences of their activities?

We cannot, however, measure everything. Instead, we have to select a few variables that we believe represent the life of the forest. These representative elements and processes are indicators. Indicators are variables that we choose to monitor. They reflect our values (*what is important?*) and our pragmatism (*what is feasible?*).

When our concern is the status of nonhuman life, or biodiversity, we are usually engaged in what is often called "baseline monitoring." The premise is that research can establish a level or a rate for some indicator that is "normal" or "original." A significant change in the indicator reflects the status of the entity being monitored. In some cases, however, as with a census of the number of butterfly species that are flying in the first week of July at a given site, we may not know the "normal" number, or even if the concept of normality applies. In such a case, the data for the first few years of monitoring constitute an inventory of what is present. With certain caveats, these census inventories can serve as a baseline for monitoring future changes. Unless there is some idea of baseline, we risk gathering data mindlessly. Data on population fluctuations are notorious in this regard.

Some indicators, such as population trends in sensitive plants and animals, may give us direct feedback on biological processes; other indicators can provide indirect information on species and processes that resist direct monitoring. The latter are sometimes referred to as surrogate indicators, and, like buoys on the sea or like one's pulse, they provide clues about what is happening beneath the surface. For example, the pH of a lake is a surrogate indicator for biological effects, such as the health of fish in the lake. The distinction between direct and surrogate indicators collapses on close inspection; they are the extremes of a continuum. Any indicator, though, can sometimes provide a basis for predicting future impacts.

The selection of indicators is as much an art as it is a science. There are several guidelines that are obvious (for a current review, see Noss and Cooperrider 1994):

1. The selected indicators should be relatively *easy to monitor*; keeping it simple also helps to control costs, especially if budgets cannot be predicted for long into the future.

2. The monitoring should pass the test of *good experimental design*, including awareness of how the data will be analyzed; the power of the statistics to be used can determine the sample sizes needed.

3. The monitoring should do more good than harm: this is the principle of *minimal disturbance*; it may appear obvious, but sometimes people are carried away by their infatuation with technology.

4. *Avoid fads*. Bandwagons should not be permitted to drive the selection of indicators; new technologies periodically sweep up scientists and technicians in the coattails of scientific fashion. The limits of new technologies should be kept in mind. Some relatively recent fads have included electrophoresis, food web analysis, and even diversity indices.

5. Indicators should monitor *processes and flows* as well as *states* and *stocks*.

6. Indicators should provide *early warnings* before it is too late to reverse the deterioration; similarly, indicators should be selected to detect possible *thresholds* of human interference that will produce rapid changes.

7. Some indicators should be dramatic. For example, *"flagship" species* such as the wolf make excellent indicators because the public understands and appreciates them. Information about the status of flagship species can, therefore, provide opportunities for educating the public about less charismatic species and processes.

8. Some indicators should be *"umbrella" species*, such as grizzlies and eagles; these are species that require large areas to maintain population viability. Umbrella species are so named because they indirectly provide habitat protection for many other less visible and less space-demanding species.

9. The list of indicators should include targets from all the relevant *ecological scales* and *levels of biodiversity*; this means consulting with a broad range of experts, including systematists, population geneticists, community ecologists, aquatic ecologists, systems ecologists, landscape ecologists, endangered species biologists, geographers, and natural resource specialists.

We go from cell to organism to population to community to ecosystem to bioregion. People have, I think, assumed that there is a corresponding spatial unit that corresponds to each level in that nest of the biological hierarchy. And the fact is that it isn't so.

10. The monitoring of chosen indicators should be an inherent component of an integrated, long-range *master plan*, which all parties, especially managers and policy makers, have had a role in designing. Without participation, there is no commitment; without commitment, there will be little or no action.

11. Finally, *the objectives should be clear to everyone*. It is not enough to state that the objective is to monitor biodiversity. For theoretical as well as for practical reasons, it is impossible to monitor every element of the forest. Because we can monitor only a few representative entities and processes, it is essential to construct objectives with care; this will help everyone understand why particular indicators were chosen. Statements of the following kind might serve as models in developing objectives:
    - "our objective in monitoring large predators is to determine if they are being harvested at a rate that threatens their viability";
    - "our objective in monitoring forest floor beetles is to assess when and where forest fragmentation is beginning to affect invertebrate faunas"; and
    - "our objective in monitoring water quality (sediment and nutrient loads, pH, coliform count, species diversity of protozoans and diatoms, etc.) is to determine where and when harvesting constraints need to be imposed."

    Statements of this type are especially helpful because *they explicitly implicate policy decisions and management actions.*

No doubt there are other useful guidelines, but the most important principle is that all monitoring of indicators should serve the greater objective—the long-term viability of populations and species and the protection of those ecological processes and habitat structures that sustain them (Soulé 1986).

Possible forest biodiversity indicators

During the course of the workshop, there were several break-away group discussion sessions. Much of these discussions revolved around the identification of species-based and system-based indicators. Tables 1 and 2 represent two "long-lists" of such indicators that were generated during individual group discussions as well as during the main workshop sessions. These lists summarize all groups' input and are not prioritized, nor do all of the items necessarily represent practical or "do-able" indicators. Some of the entries deal with very specific measures, whereas others involve the construction of broad suites of indicators, models, or data bases. There is some overlap both within and between Tables 1 and 2. Some of the indicators listed clearly require a great deal of thought and in some cases considerable additional research and development to implement. We choose to repeat them here for the record and perhaps to provide a starting point for future efforts by others who are trying to deal with the subject.

There's really no difference between species management and ecosystem management when you look at them carefully. We've artificially polarized ourselves by thinking it's one or the other, when in fact it's a continuum.

The following summarizes some of the workshop discussions that took place during the development of the species-based and system-based indicator lists (Tables 1 and 2).

Species-based indicators

One of the break-away groups expressed concern about sizes and fragmentation of tree species populations. Ideally, genetic resources management strategies should be prepared for all species, whether threatened or intact. However, given limited resources, the focus should be upon eroded or threatened species. There was a need to choose indicator species that are representative of a particular strategy of resource or landscape use. An effort should be made to select representative species from a range of habitat types and sizes (terrestrial and aquatic, large and small home ranges). This could include medium-sized to large carnivores (e.g., wolverine, fisher, wolf) and a salamander or group of salamanders (e.g., potential sensitivity to ultraviolet radiation, users of coarse woody debris).

From the perception of a chestnut-sided warbler, old-growth forest may well be a disaster. If there's not an adequate supply of young forest for it to live in and continually colonize, then that population is not going to make it.

Another group emphasized making better use of currently available data bases and linking the activities of professional and amateur taxonomists: the Forest Insect and Disease Survey (FIDS) of CFS already contains a wealth of information; there should be a focus on better quality information for biodiversity monitoring in the future.

Table 1. Species-based indicators.

- Spatially distributed habitat suitability models for rare, threatened, endangered, and vulnerable species, including the monitoring of change
- Spatial distribution of habitat specialists
- Annual updates of rare, threatened, endangered, and vulnerable species lists
- Adding nonvascular plants (e.g., fungi) to lists of rare, threatened, endangered, and vulnerable species
- In-depth measures of selected rare, threatened, endangered, and vulnerable species
- Degree of population fragmentation and size of selected species
- Monitoring medium-sized to large carnivore populations
- Measures of relative abundance of all bird species spatially and by habitat type
- Definitions of appropriate guilds and the determination of guild representativeness in given landscapes
- Harvest levels of fish and wildlife
- Measures of habitats disturbed by beavers
- Measures of insect guilds related to forests but not restricted to commercially important pests
- Annual updates of new species per year and per geographic area
- Measures of extant vegetation and disturbance regimes
- Measures of environmental space (niche) and geographic space occupied by organisms
- Identification and monitoring of lichen species specific to old-growth forests
- Measures of below-ground species diversity, including numbers and abundances by ecosystem type
- Changes in tree species by forest cover type and/or ecosystem type over time
- Proportion of tree species that have a gene conservation strategy in place
- Measure in situ and ex situ genetic conservation strategy of tree species
- Measuring/monitoring taxa that perform an integration function (e.g., amphibians, salmonids, new tropical migrants, nocturnal moths, forest floor beetles)
- Absolute population levels (estimates) of selected species guilds
- Measures of genetic diversity of forest plantations
- Measures of stress in populations/species
- Changes in vegetation/species distributions on private land
- Toxic compound levels in wildlife

Table 2. System-based indicators.

- Access vs. nonaccess roads, including type and density
- Use of access as an indicator of "wildness" quality
- Fire disturbance: area burned frequency and amplitudes of fires
- Insect disturbance: area impacted frequency and amplitudes of outbreaks
- Number and percentage of exotic species
- Changes in forest cover (type, age class) within bioregion or ecosystem type
- Changes in harvesting systems, including adoption of new technology
- Trends in size of clearcuts
- Regeneration success of harvested areas inclusive of vertical structure and composition
- Areal extent of different age classes
- Harvest levels as proportions of primary productivity
- Representativeness of ecosystems protected and measures of protected lands
- Indices of landscape composition heterogeneity and configuration
- Changes over time of ecosystem processes (e.g., decomposition)
- Measures of connectivity between protected spaces; degree of isolation
- Measures of water quality and flow regimes (e.g., chemistry, physics, organics, temperature)
- Energy consumption levels in ecosystems
- Measures of climate change
- Measures of nonbiotic rarity
- Use of growth and yield data to measure site quality and change over time
- Measures of plant vigor
- Adherence to acceptable forest management practices
- Public expenditure on spatially related research and development and forest management
- Levels of pollutant loadings within ecosystems (e.g., acidic deposition)
- Trends in deforesred riparian habitats and changes over time to wetlands
- Land alienation (e.g., flooding)
- Measures of below-ground structure and function (e.g., soil microflora and microfauna, mycorrhiza)
- Changes in soil productivity
- Measures of structural components at risk (e.g., snags, logs)
- Areal extent of habitat at risk for selected guilds
- Measures of diversification in forest-based livelihood
- Measures of robustness of ecosystems to absorb impact
- Canadian policy decisions and effects on biodiversity of other countries
- Measures of government policies that run counter to biodiversity conservation
- Measures of Canada's biodiversity relative to other countries'
- Recreational usage of forests and effects on biodiversity

This group suggested certain "integrative taxa" for monitoring: large carnivores, salmonids, noctuid moths, forest floor beetles. Lichens, amphibians, and freshwater fish can serve as "early warning" indicators. In Australia, a monitoring program called "Frog Watch" has attracted much public involvement. There is a need to consider international linkages (e.g., the network of taxonomic experts organized by the Commonwealth Agricultural Bureau, which provides services to developing countries such as Costa Rica). Harvesting and trapping data are often flawed but still useful for certain species. Monitoring of soil organisms would require considerable additional research and expertise and is perhaps more feasible in an agricultural context.

I think that at least there's some element in the public's mind that this 12% set aside is some penance that we're paying to allow us to continue to do what we've done on the remaining 88% of the land. That should not be what we're after.

System-based indicators

One group made a number of specific suggestions for indicators, including:

- harvest levels and patterns—use access roads as an indicator of "wildness," hunting pressure;
- disturbance—natural and anthropogenic (forest fire intervals, changes in tree species composition, spread of exotics);
- composition, structure, and configuration of forest cover, using georeferenced data;
- physical properties of water biological oxygen demand, organic compounds, sedimentation—consider using Australia's "Water Watch" program as a model for public involvement;
- primary productivity (some debate on this, growth and yield data are often in private hands, may be inaccessible);
- climate change—use of organisms as indicators of climate change remains largely a research problem; and
- levels of expenditures, policy decisions—there could even be a "Biodiversity Auditor General."

Another group emphasized the importance of "backcasting," trying to estimate changing amounts of forest, age class distributions, patch sizes, and so forth. By combining species- and system-based lists, indicators of composition, configuration, and connectivity can be generated. These indicators, when given a dynamic aspect, are transformed into landscape processes. However, an extensive, georeferenced data base of landscape processes would not answer all questions. Data collected at a network of sites over time on, for example, pollution loading, soil processes, plant vigor, and water yield, provide the "vital signs" of ecosystems. This may ultimately allow modeling, giving monitoring a predictive capability.

There were some interesting analogies drawn during the discussions. Michael Soulé made the point that society is saying we aren't doing the right thing—what should we do? Scientists often respond, "More research is needed, we don't know enough." But we are in the positions of surgeons faced with a situation that requires triage. We can't say, "Gee, we have never seen this before" and go back to medical school. We have to make decisions and have some tolerance for uncertainty.

Just because we have this fashionable term "ecosystem management" doesn't make things any easier, in spite of what a lot of politicians would like to believe.

Winnie Kessler cautioned that if people fall back on a medical analogy, problems may arise unexpectedly. It is better to train people to be observant, to encourage public involvement, to take people's concerns seriously. Michael Soulé noted that the uncertainty regarding the behavior of natural systems increases with the length of record. Confidence intervals around trends often grow wider with more data, not narrower.

Nik Lopoukhine commented, "We thought we'd died and gone to heaven when managers began to use ecosystem management, but then it became clear that this meant 'harmony' and more tourism. We nonetheless are getting more ideas in via the ecosystem management concept." Richard Sims said, "It's like juggling plates—how many are in the air, and how many are left on the table?" Michael Soulé replied, "But the danger is that the 5% of species lost are the large vertebrates when people argue 'We can't save them all.'" Dan Welsh asked, "What should we focus on?" Soulé suggested, "We can't save ecosystems: we should, as Aldo Leopold said, save all the parts." Evelyn Hamilton noted that "species go extinct anyway—isn't there a danger of trying to save species that can't be saved?" Soulé replied that the natural rate is for one vertebrate to be lost every 1000 years; all extinctions in recent years are anthropogenic.

You can't cookie-cut this country ... a universally acceptable classification scheme of ecosystems does not exist .... There are an infinite number of ecosystems, and we just arbitrarily say we'll stop subdividing at this point. I mean, I've got an ecosystem in the dirt under my fingernail.

The third group expressed a preference for a monitoring approach that would focus on maintaining habitat for species at risk. This might mean the areal extent of habitat patches that could potentially be occupied. Although some habitats would be lost, the intent would be for a minimum level of protection to remain. There might be criteria for minimum amounts and distributions of critical habitat species in different ecosystem types. This would be determined by monitoring vegetation trends. For example, as a surrogate for monitoring carabid beetles, one would monitor important elements of the habitats they are known to occupy. Actual beetle monitoring would be only on an experimental basis.

It was noted that networks of volunteer participants in the biannual bird counts and herpetofaunal surveys are of critical importance. Monitoring networks should be able to collect data on a systematic basis; some indicators will take advantage of existing data, whereas others will involve new resources. The monitoring of beetles, moths, and pollinators may not be supported by the level of taxonomic expertise currently available. Furthermore, the public does not generally like organisms that are neither furry nor feathery. However, the opportunities for making use of volunteers for data collection should be explored.

A point was made that only spatially aggregated data are needed at the national level: how many kilometres of roads, how many hectares of clearcuts; only the bioregional level requires spatially explicit data. Evelyn Hamilton suggested that the basic data will be the same no matter what spatial scale is examined. Indicators may be valid at any level; the question is how they will be reported. Richard Sims replied that there may be a need to tie findings to a specific location, even when reporting is done at the national level. Charts and tables may simply not be adequate.

Winnie Kessler described an experience that occurred in the U.S. Forest Service, which undertook a major public land use planning exercise that took 10 years, cost tens of millions of dollars, and generated endless tables, graphs, and charts. The public said, "No, we want to know the cumulative effects in time and space." They did not want data on resource stocks, flows, and harvesting activities. They wanted to know the state and condition of the resource. At the time the exercise was conducted, the U.S. Forest Service did not have two things that we have today: first, we now know that biodiversity is an issue and that we must focus on the condition of the land; second, we have new tools that can show what the land looks like (e.g., geographic information systems [GIS], temporal remote sensing data bases). The critical point may not be how many animals were shot or trapped in a given area, but whether a particular species was seen there.

Henry Nix pointed out that primary attribute data are essential to create visual indicators wanted by the public: the question then becomes what to create. GIS, or automated cartography, is not just a new tool, but a new paradigm: a new way of thinking about landscapes. Mick Common suggested that there are three distinct viewpoints that in turn generate different questions: those asked by researchers, managers, and the general public. Starting with highly disaggregated data and working upward may be the wrong way to go; he noted that "this is well established in economics." Henry Nix made the observation that data, information, knowledge, and wisdom all represent different levels of understanding. We're seeking that "odd drop of wisdom." He added that the discussion was slipping around between data, information, and knowledge and that this causes confusion. Bill Bourgeois stated that "you can't just throw out information, you have to provide some interpretation." Michael Soulé noted that interpretation is fine as long as you let advocacy groups and academics also have the data so they are able to make their own interpretations.

A conceptual framework for the development of indicators

When tackling any complex, multifaceted issue, it is useful to develop a compartmentalized framework or model that simplifies the components and helps to clarify their interrelationships. The workshop participants collectively developed a framework that identified major components of a biodiversity indicators system. Figure 1 is a schematic conceptualization of that framework. The two major elements are *Drivers of Change* and *Attributes Inventoried and Monitored.*

The framework includes, as a central theme, the temporal and spatial components upon which biodiversity must be measured and understood. Operating upon these two gradients are outside forces that effect change (referred to as Drivers of Change). Drivers of Change essentially refer to management actions, such as land logged, road development, harvest levels, and regeneration efforts—and those Drivers of Change that are not so expressly deliberate. There are a large number of ecological (biological) and other processes/functions/actions that are responsible for (i.e., "drive") ecosystem health and operation and that, over temporal and spatial scales, can interact to effect and direct change within ecosystems. There are two distinct categories of these system drivers. The first category is those that can be considered to be "natural effects" and are ecological processes that continually or regularly occur within or to forest ecosystems. The second category is "anthropogenic effects," either intended or not. These could include factors such as climate change, pollution, and other stressors. The purpose of distinguishing these classes of drivers is that some are under management control and others are not.

It is also possible to distinguish Drivers of Change from reporting on change. Monitoring the effects and their magnitude and evaluating impacts of change are different activities that can be based more on interpretation than on the processes or reactions that are involved.

Attributes Inventoried are the intended and unintended consequences of management actions on biodiversity at the site, stand, and landscape levels. Attributes Inventoried are explicitly the elements of biodiversity we are interested in. The temporal gradient moves from past to present to future. Ideally, indicators could be constructed to characterize conditions at any point in time—i.e., not only have a descriptive/monitoring role but also provide backcasting and predictive capabilities. Changes should in fact be determined, measured, reported upon, or predicted over time.

The role of spatial (geographic) scale is represented in the central part of the diagram through reference to site, stand, and landscape. Many of the processes and actions that effect change in forests operate across a range of resolutions. It is generally appreciated that ecosystems come in different sizes and are looked at quite differently at different spatial scales; typically, one set of ecosystems is nested within others in a

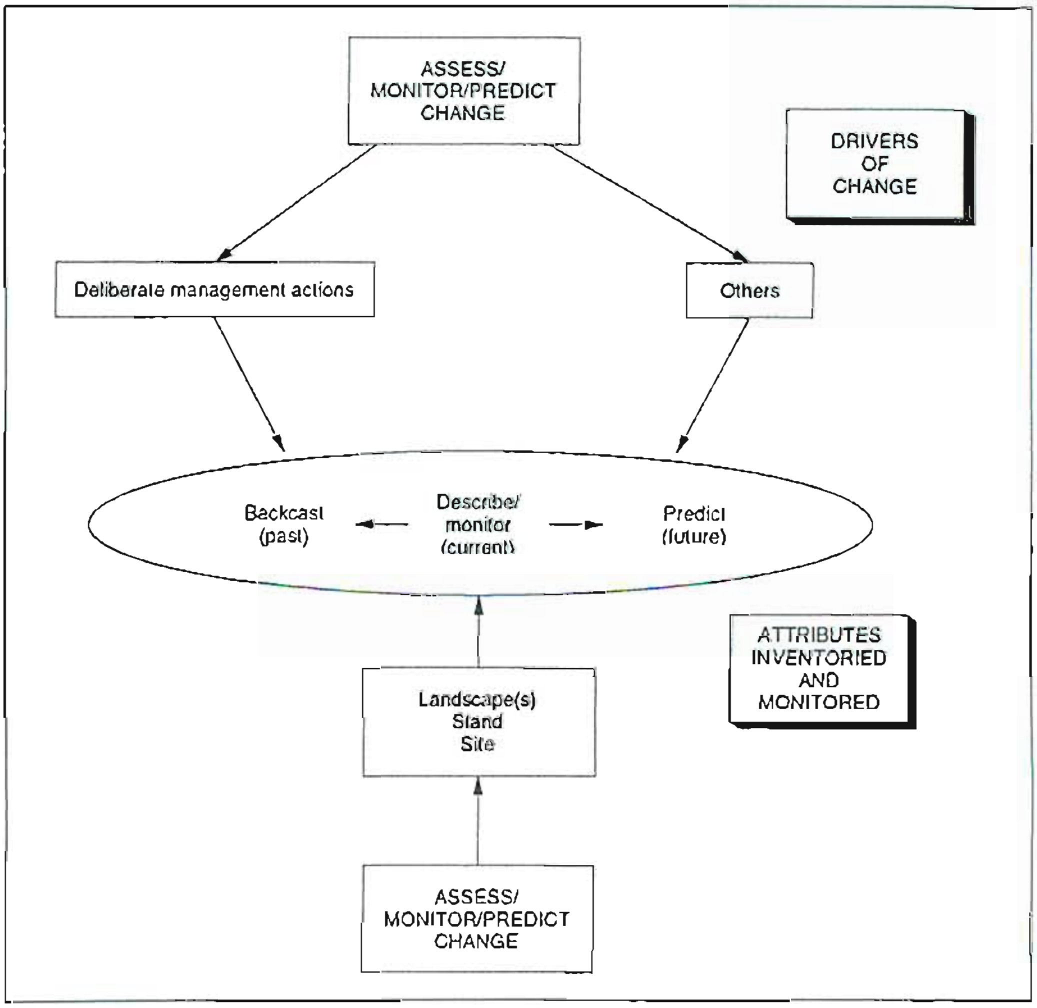

Figure 1. Towards a framework for biodiversity indicators.

hierarchy of spatial sizes. However, species often cross ecosystem boundaries. Because of the linkages that exist among ecosystems and species across scales, modification of one ecosystem is likely to affect the operation of surrounding ecosystems and species occurring in each. Drivers of Change that affect larger ecosystems, for example, will usually affect smaller, adjacent, and intrinsically linked ecosystems (e.g., downstream effects of logging). The relationships of spatial scales are such that one must understand the aggregations upward and the subdivisions downward in order to make informed decisions about ecosystem/species interactions. We, in fact, need indicators that can provide information and operate at various spatial scales, from broadest to finest.

This framework (Figure 1) provides a conceptual basis for considering those complex interactions that together define forest biodiversity in Canada. However, the scheme presented is just one way of envisaging the multidimensional components and interrelationships that may be involved. Such a framework, nonetheless, clearly indicates that the dynamics and elements are indeed interdependent and complex.

Moreover, it may be more readily appreciated that there are at least three main "types" of forest biodiversity indicator:

- indices that represent basic measurements of biotic and abiotic conditions;
- indices that are measurements of ecosystem drivers; and
- indices that are most appropriately recognized as measurements of other components and require some interpretation or calibration.

Table 3 represents the participants' "short-list" of possible indicators based on considerations of:

- the *significance/value*;
- general impressions on *practicality*;
- the *scale* of the indicator (national, regional, local); and
- the degree to which the indicator could be used as a *predictive* as well as a *descriptive* tool.

Table 3 explicitly links back to Figure 1 and has been divided into two categories: *Drivers* and *Attributes Inventoried and Monitored.*

Table 3. Biodiversity indicators: a short-list.

Drivers

- Area logged and harvest levels summarized by bioregion or ecological area
- Roaded land, including type, density, and effect on wilderness quality
- Measures of fire and insect disturbance regimes, including area, frequency, and amplitudes
- Policy disincentives
- Measures of climate change
- Measures of water quality and flows
- Changes in soil productivity
- Measures of stress, including pollutants (e.g., acidic deposition, toxic compounds in wildlife)

Attributes Inventoried and Monitored

- Indicators for forest trees (genetic diversity, changes in vegetation on private lands, harvest levels by species, etc.)
- Indicators for other taxa, including carnivores, amphibians, lichens, and noncommercial tree and plant species (determining population levels, describing trends and shifts over time, etc.) by bioregion or ecological area
- Indicators for rare, threatened, endangered, and vulnerable species (e.g., annual updates of lists)
- Patch and landscape measures of composition, structure, and configuration

General recommendations

A number of more general recommendations arose out of the workshop discussions. These are summarized below.

Biodiversity conservation in Canada

- There is a need to identify the "starting point," the "time zero," or the "temporal baseline" for the measurement of biodiversity conservation.

- National biological inventories should be strengthened in Canada to provide a more thorough understanding of the numbers and types of organisms in ecosystems and how these contribute to overall biodiversity. The fundamental biological characteristics (e.g., genetic strains, species, ecological assemblages) must continue to be studied to determine their characteristic abundances and distributions in the landscape.

- It is important that long-term ecological research be continued and intensified, particularly in the areas of composition, structure, and function.

- Biodiversity conservation needs to be incorporated into both shorter- and longer-term resource management plans.

- A major challenge for biodiversity conservation involves the appropriate management, application, and communication of scientific information.

- There should be stronger support for multidisciplinary scientific research programs on biodiversity in Canada.

- Computer modeling must be a critical part of the way we address biodiversity conservation between species and ecosystems because of the many unknowns and complex interactions.

- Scientists, resource managers, and academicians have a responsibility to continue to work towards scientifically based knowledge and trend away from intuitive approaches to biodiversity conservation.

- In developing and using forest biodiversity indicators, Canada must be cognizant of steps and directions being taken in other countries and should continue to participate in, support, and, where appropriate, lead the development of global strategies for reporting and monitoring elements of biodiversity.

- Administrative and electoral boundaries (federal, provincial, and municipal) should be included among the geographic stratifications for the interpretation phases of the spatial information associated with biodiversity indicators.

- A visual aspect to an indicator is a useful attribute, and, wherever possible, this mechanism should be used to help convey the information provided by such indicators.

- The development of suitable indicators for forest biodiversity conservation must not be done in isolation from other resource sectors and other ecosystem conditions.

- The development of a substantive list of forest biodiversity indicators is not something that can be done casually. Before specific indicators are finally selected, there will likely be a need for a series of workshops dealing with specific aspects (but inclusive of numerous disciplines and viewpoints), consultations, some detailed thought and reflection, and maybe even some entirely new research and development tasks.

The development of biodiversity indicators for forests in Canada

- The development of indicators requires a clear articulation of the spatial scales involved (i.e., global, regional, and local) and the implications of taking that particular perspective.

- The development of a comprehensive list of biodiversity indicators is complex: the process requires that there be representation of the net effects of intricate, detailed interactions of biological organisms (and complexes) across a spectrum of geographic and ecological conditions, a broad range of hierarchically nested and non-nested spatial scales, and a spectrum of temporal dimensions.

- Defining suitable indicators for biodiversity conservation requires that specific hypotheses, frameworks, and objectives be clearly articulated. There should be an accepted "standard" or "construct" of what represents essentially a pristine, healthy, desirable condition. The direction of the indicator then needs to be compared with this benchmark, to determine its direction and rate of change (e.g., is it unchanged, trending upward or downward, or perhaps oscillating within some range or across some standard pattern?).

- Indicators should be constructed such that if future trajectories are projected, they can be related to alternative management scenarios.

- It is probably critical that the indicator framework be constructed in concert with the development of a system for longer-term monitoring (i.e., indicators of biodiversity change should be applied in the context in which they are to be periodically assessed).

- At the overview level, there is a requirement to identify perhaps only 8–10 indicators that can be used to generally describe and represent the "overall biodiversity state of Canada's forests." Despite this, the scientific community must continue to strive to develop and then improve indicators that have long-term and substantive application.

- There should be a strong emphasis on further research and development in the use of spatial analysis tools such as GIS and remotely sensed data. These technologies will be fundamental to the development of species and ecosystem biodiversity indicators in Canada.

- Formal sets of recommendations need to be developed for resource management agencies that describe how to collect, record, and present various data types and data elements that have biodiversity indicator value in Canada (e.g., accurate geocoding). In doing so, it is important to include data types that may not be immediately practical but may be of potential use in the future. Data should also be made widely available in digital or computerized form.

- A nontrivial issue is to determine the time periods that will be required to update forest biodiversity indicators. Biodiversity indicators are not costless.

- Efforts should be made to involve and utilize the public and volunteer organizations in data collection and monitoring programs. This could help lower costs and perhaps as importantly be an education mechanism.

- The development of some biodiversity indicators should occur in pilot studies—i.e., within distinct geographic areas where conditions can be carefully monitored and measured, results scientifically replicated, and predictive models tested and calibrated.

- More attention needs to be given to genetic biodiversity issues. For example, the northern boreal forests generally contain few, but widespread, species. The nature of their genetic diversity is not well known but is believed to have a great influence on forest ecosystem dynamics and function.

- There is a need to acquire better information on the ecological requirements and autecology/synecology of intraspecies relationships, in particular for species that are both widespread and common and for those that are rare and/or endangered.

- Using species-based indicators for conservation is essentially target species management. In the context of a number of species-based management scenarios, there remains the problematic issue of prioritizing species. Research is required in this area.

- There is a fundamental need to examine the total geographic and ecological distribution of an organism if it is to be fully understood for the purposes of using it as an indicator of biodiversity. Within-species ecotypic variation is not well understood for many species that could be suitable candidate indicator species. Species-based biodiversity conservation cannot be accomplished solely in a regional or local context.

- There is a need to go beyond purely species-based indicators; this being said, species-based measurements must be included as a component of a suite of biodiversity indicators to contribute to the overall perspective.

- In addition to a species-based approach, a complementary set of measurements is required to describe overall system health, viability, processes, and dynamics. Ideally, these indicators would also serve as a "safety net" for those taxa that we will never study and that we may perhaps never even know exist.

Selected summary comments by workshop participants

Winnie Kessler remarked that "what's important is that biodiversity has national attention; it's a political issue." We as scientists know the complexity of the data needs. Interdisciplinary teams and forums are very useful. The national desire to know must be addressed.

Henry Nix said, "I enjoyed the discussions very much. In my country, biodiversity is the preserve of biologists and ecologists, and not research managers. This meeting was framed and placed in the context of a major user of the forest resource."

Michael Soulé remarked that he felt privileged to have been at the meeting and had learned a lot. He raised a point not mentioned earlier—a need to keep data on the kinds and species of trees milled. He noted that he forbids his students to use the words "niche" or "ecosystem," because they can become "garbage cans for a wide variety of concepts."

Harry Hirvonen described the discussions on indicators at the deputy minister level. There was an initial desire for a single environmental indicator at the national level; now the target number is 8–10. He noted that there had not been much discussion about the social and economic context of biodiversity during the workshop, but that Environment Canada's State of the Environment Reporting faces this all the time.

Carlos Galindos-Leal indicated that the workshop had reached a useful focal point for the development of regional conservation plans. It is important to keep in mind the audience for reporting; we tend to represent views of scientists and perhaps some managers, and it is potentially dangerous to assume what the public knows and what it wants.

Judy Loo noted that there is a balancing act involved: "there's a danger of glossing, of being too simple; but there's also a danger of saying too much with data of limited scope or poor quality."

Bob Footit said, "As one of the taxonomists who has to put names on biodiversity, I'm daunted by the amount of work remaining to further develop these indicators." He noted that the term "species" is used a lot, but taxonomists can rely only on an operational concept. He stressed that taxonomy relies on getting a broad data base. "We develop classification schemes, look at variables for identification." First, it is necessary to establish patterns and relationships; then indicators can be developed. A "key character" for identifying an organism is often just a convenience. Taxonomists often talk about phylogenetic diversity as the interface between historic processes and current status. Lots of information is built into the evolutionary relationships on phylogenetic trees. When we discuss regional and national perspectives, we should consider that local processes are conditioned by what we know in the global perspective of the taxa in question. There is a danger of developing biodiversity indicators that are regionally useful but do not provide a global perspective.

Margaret Penner said that both the indicator short-list and the framework model were good, but she was concerned that the future contained only more monitoring. She saw a need for prediction: what are the impacts of reduced pesticide use, more selection harvest, and so forth.

Dan Welsh agreed that the framework was a good synthesis of our efforts. He said he had always thought of himself as a species-oriented conservation biologist but had found himself talking in terms used by forest engineers. He said that "biodiversity" is

I'm glad I don't have to report on bioindicators and I don't have to manage biodiversity; I just manage people who describe biodiversity, and that's bad enough.

not the goal; it is the conservation of biological resources. He felt that modeling aspects had not been given sufficient attention: "with another half hour we might have done more!"

Evelyn Hamilton said that she had been reflecting on some changes over the past two years. In British Columbia, the focus has shifted from old growth to biodiversity. "Sometimes we talk about biodiversity when we mean spiritual values—maybe in two years we'll be talking about Canadians' state of spiritual health."

Jim Farrell concluded by responding to Bill Bourgeois' comment about the need for a master plan, some grand design: "Out of this chaos, some sense of order will be created...." We hope these proceedings represent a good step away from the chaos!

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Towards a Set of Biodiversity Indicators for Canadian Forests

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Introduction

As mentioned in the Introduction of the Workshop Results section, an earlier version of this paper was given to the participants prior to the workshop. The purpose was to provide background for the workshop and to identify and focus discussion on some of the major issues involved in the development of indicators. The document was intended not to limit discussion, but rather to define a suitable framework for the workshop.

Values associated with biodiversity

Ultimately, biodiversity indicators are required to provide feedback to decision makers and the wider community on the impact of land use and resource utilization. All policy and management decisions unavoidably involve relative valuations of the full range of forest services, including the conservation of biodiversity. A brief discussion of values associated with biodiversity sets an appropriate context for the scientific discussion that follows.

Biodiversity conservation is a component of ecologically sustainable development. Following Blamey and Common (1992), the planet's biodiversity serves at least four functions of interest to humans:

- provides resources that are used in the production of goods and services;
- assimilates wastes that arise during both production and consumption;
- provides services that are directly consumed (these can be broadly defined to include amenity services, natural beauty, and the maintenance of traditional cultures); and
- provides the basis for the maintenance of ecosystem functions that support human life.

In addition, maintenance of biodiversity

- provides an underlying continuity to the evolutionary lineage of life on Earth.

These values encompass direct and indirect consumptive and nonconsumptive perspectives; that is, they may involve direct uses such as timber harvesting or indirect uses such as the maintenance of watershed filtration functions. The first four values are anthropocentric and therefore can be defined as economic in nature. The fifth value may not necessarily lead to improvement in the physical well-being of humans; rather, it represents the view that species other than humans have a right to exist and evolve.

Perrings et al. (1992) distinguished three types of economic value:

> The first is a concept of value that corresponds to the notion of incentive. A market price is only one example of such a value, although for convenience we typically refer to market prices and incentives as if they were interchangeable. The second is a concept of individual or private value, which is the value that biological diversity has to individual human users. The third is a concept of social value which is the aggregate impact on the welfare of all individuals in society, both now and in the future. The importance of the distinction between these concepts of value is the following. The market value of biodiversity is what informs the billions of independent decisions that are directly responsible for most of the biodiversity loss that is occurring around the world. But the market value of biodiversity loss does not measure the change in social welfare associated with that loss.

Perrings et al. (1992) went on to address some of the reasons for the difference between market and social values. An obvious point is that many values are not made explicit via market transactions. Clearly, many environmental goods and services exist outside of markets, and relative valuation can be problematic. Economists have in recent decades begun to address the issue of total value (i.e., both market and nonmarket values). Numerous techniques now exist that can, in principle, be used to derive quantitative estimates of some of these nonmarket values (see Randall 1988; Brown 1990). It is fair to say that even though the techniques are becoming widely used, they are not necessarily widely accepted. There is some controversy regarding reliability and validity in different contexts (for examples and differing views, see Peterson et al. 1988; Blamey and Common 1992; Kahneman and Knetsch 1992; Smith 1992; Common and McKenney 1994).

To be most helpful, biodiversity indicators should be developed within the context of the decision-making process. Although this workshop is not addressing relative values, we are attempting to derive better physical measures of the status of biodiversity conservation so as to better evaluate trade-offs between competing values. It is worth noting that trade-offs exist between the various components of biodiversity. For example, the management of an area for a rare or endangered species may result in the loss of other species. Such decisions inevitably reflect either explicit or implicit decisions about relative values.

Components of biodiversity

Clearly, before valuation problems can be addressed, it is necessary to characterize the extant biodiversity of Canada's forests and evaluate the direct and indirect impacts of human land use, resource utilization, and environmental change on the character and viability of forest biodiversity. A baseline is required to determine whether human activities are degrading this baseline such that "biological impoverishment" (Woodwell 1990) is occurring. The degree of biological impoverishment may be taken as a relative estimator of the ecological sustainability of development activities and policies. As noted above, the maintenance (and replenishment where impoverishment is severe) of biodiversity will involve trade-offs between competing land uses, choices between different components of biodiversity, and the use of society's resources in general.

Defining what constitutes the "baseline" is a complicated task. One possibility is to use what Ray (1988) called a system's characteristic biodiversity. Characteristic biodiversity is a somewhat illusive term, but it can be defined as follows: the biodiversity that occurs as the result of the interaction between biota, the physical environment, and the natural disturbance regime, in the absence of the impact of modern technological society. Hence, we can say that the characteristic biodiversity of the coastal forests of British Columbia is very different from that of the boreal forests of northwestern Ontario—there are different dominant tree species and understory plants; process rates are different (e.g., growth rates are faster on the Pacific coast); the dominant physiognomic structure of the vegetation differs; etc.

Much of Canada's forest environment has been altered since the advent of modern technological society, by both anthropogenic and nonanthropogenic sources. In fact, the biodiversity of Canada's forests has been affected since European settlement, and before that by the First Nations people. This suggests three potential baselines: pre-First Nations; preindustrial; and extant.

Once a baseline is established, the impact of current human activities can be assessed. For example, we can ask what impacts modern forestry practices are having on the long-term structure and function of boreal forests. Are species becoming more endangered? Is the viability of populations being threatened? Are we creating or designing forests that are structurally and floristically simpler? Is the productivity of the forest ecosystem being maintained, or is there, for example, a significant net loss of nutrients and biomass from the system?

To operationalize a set of indicators, data must be collected and analyzed and an inventory developed and maintained. A critical step is to define both the *biological* and *spatial units of analysis*. These definitions must be soundly based in the relevant sciences—genetics, population ecology, community ecology, landscape ecology, and the earth sciences—and be clearly linked to the objectives of the exercise. Consideration of the effects of scale, disturbance regimes, and the role of the physical environment is required. Once an appropriate set of scientifically sound and useful indicators is defined, the problem remains of determining the availability and quality of data and the resources and mechanisms required for data analysis and utilization. The following sections discuss these factors in turn.

Species diversity

Species diversity can be defined in terms of species richness, abundance/dominance, and evenness and can be examined at different scales—so-called alpha, beta, and gamma diversity. Alpha is a measure of diversity within communities, beta measures the diversity between communities along some kind of environmental gradient, and gamma measures diversity based on all communities within a geographic region. Several questions arise from applications of species diversity indices (SDIs). The units of analysis for SDIs are not standardized—they are sometimes habitats, communities, or even ecosystems (e.g., Buzas 1972; Samson and Knopf 1982; Cowling 1990; Noss 1990). Often they are more simply different vegetation associations or landform units with a different physiography. How different do the biophysical characteristics of two sites have to be in order for beta diversity to apply? How far away do two plots have to be for gamma diversity not to apply? There is no standard protocol for survey design, sampling, and analysis.

Landscapes naturally vary in terms of the number and types of species they support. Tropical forests are vastly more species diverse than boreal systems. The fact that the latter are relatively species poor does not necessarily lessen the importance of their contribution to the planet's biodiversity. Interpreting species diversity depends on knowledge of the system's total structure, composition, and processes. Spatial context and ecological context are therefore needed to interpret the significance of species diversity. Various mechanisms have been proposed to account for the spatial variation observed in species diversity, including:

- disturbance/stability (in particular, the frequency and intensity of disturbance and the amplitude of environmental variability);
- predation and competition;
- productivity;
- physical environmental gradients; and
- historic biogeography.

Locally, diversity has been associated with disturbance regimes. For example, Abugov (1982) suggested that the frequency of population reductions and the growth rates of competitors are important factors—low population numbers reduce competitive differences, and hence diversity can be maintained by periodic population reductions; faster growth rates for competing species reduce diversity owing to enhanced competitive displacement. Fire is one mechanism that could prevent competitive equilibrium from being reached. Similarly, predation theories of local diversity predict that in some circumstances predation can promote diversity by reducing competitive exclusion. Various authors (e.g., Huston 1979) have suggested that local diversity is maximized at intermediate levels of disturbance, as disturbance allows the maintenance of competitively inferior species.

It follows from the disturbance/predation/competition theories that local diversity is higher where "productivity" is lower (owing to low population densities and therefore a low rate of community displacement). However, the productivity theory of diversity presents an opposing viewpoint, where diversity increases with increasing net primary productivity. The difference between temperate and tropical systems has been used as evidence in support of this theory. Jordan (1983), however, demonstrated that the main difference between tropical and temperate systems lay in foliage production rather than wood production. Greater foliage production results in an increase in the complexity of the vegetation's vertical structure, which in turn creates more niche opportunities. Interestingly, Sims et al. (1989) found that the structural diversities of boreal forests in northwestern Ontario (in terms of shrub- and herb-rich sites) were greatest on the most productive sites—i.e., where moisture and nutrients were not limiting. Stability theories argue that diversity is promoted by the stability and longevity of the ecological conditions in an area (e.g., Ross 1972). However, these are perhaps more relevant at the continental and regional, rather than local, scales of analysis.

Regional species diversity can be related to the "slope" of physical environmental gradients. For example, if mesoclimate varies significantly over a relatively short horizontal distance, then regional species diversity can be expected to be high. In British Columbia, for example, a west–east transect encounters a warm, wet coastal zone, then wet, cold mountains, through to drier, warmer inlands. These physical environmental gradients are accompanied by equally significant variation in vegetation composition and structure (Krajina 1965).

At a broader scale still, species diversity can be related to the actual processes of speciation. These are primarily genetic mutation and recombination; and geographic isolation and colonization. Most of Canada's biomes were obliterated by ice sheets during the geologically recent Pleistocene series of ice ages. Most species have recolonized the country over the last 10 000 years (i.e., following the most recent ice retreat). Hence, many ecosystem processes, such as those relating to soil development, are relatively youthful (compared with, for example, the arid parts of Australia). There has therefore not been the time for geological and other events to occur and isolate populations, as there has been in the tropics.

There is clearly no simple interpretation to species diversity. Its significance can be evaluated only in the context of a specified space/time scale, and only where the relative roles played by disturbance, predation/competition, environmental gradients, heterogeneity, and productivity are clearly understood.

Intraspecies diversity

Local adaptations represent an aspect of intraspecies genetic variation that is closely related to spatial gradients in physical environmental regimes. For example, there are thought to be two ecotypes of black spruce: "lowland" and "upland" (V.F. Haavisto, CFS, pers. commun.). The lowland variety occupies wetter sites and has slower growth rates and wood yield than the upland variety. Although less important commercially, eastern white cedar also exhibits distinct lowland and upland ecotypic variation (Habeck 1958). In forestry, artificial regeneration may result in the use of seed that is not adapted to local climatic conditions, with subsequent poor regrowth or even increased risk of mortality.

For both plants and animals, a hierarchy of populations can be recognized. For example, some number of individuals may occupy a given habitat patch. Numerous suitable habitat patches could occur within the local landscape, with varying degrees of occupancy. If the patches are all within the home range of the organism, then these populations can be grouped as a metapopulation. Examining a larger area, the region may support a number of these metapopulations. The greater the environmental difference between the habitats of populations and the longer the time passed since these populations dispersed, the greater is the potential for genetic variation as a result of local adaptation.

Genetic diversity (as measured by, say, an index of heterozygosity) may or may not be related to the fitness (as measured by the vigor of growth and reproductive success) of an organism or the viability of a population. Among the factors that should be considered are genetic load (potential for inbreeding depression) and outbreeding depression (possibly related to genetic coadaptation; Templeton 1986). Although individuals within a homozygous population may be fit, the population may be susceptible to environmental stress and change. Hence, heterozygosity can at times be advantageous. Heterozygosity can be compromised in outbreeding plants owing to forest fragmentation, as populations, sizes of native forest species, and migration among patches are reduced (Ledig 1986).

Many boreal forest plant species are widespread and abundant. It can be argued that to conserve these species would require maintenance of the genetic variation found between the populations. Both genetic diversity and genetic variation, owing to local adaptations, may be mechanisms that help maintain ecosystem resilience and stability.

In summary, every (noncloned) organism has a unique genetic blueprint. In terms of the genetic dimensions noted above, a population can be expected to be to some degree distinct from every other population of that species. In some circumstances, therefore, populations rather than species may be a more appropriate biological unit of analysis for the conservation of biodiversity.

Rare and endangered species

Public concern over the loss of biodiversity is often expressed in terms of the need to protect rare and endangered species. With increasing frequency, special legislation is enacted to protect species so defined. Rabinowitz et al. (1986) suggested that there are three dimensions to rarity:

- the geographic range of the species;
- the habitat specificity of the species; and
- the size of the local population.

Habitat specificity can be defined in terms of the ecological plasticity and tolerance of the species, in association with the availability of suitable habitat.

The definition of rarity therefore demands a spatial context. Forest songbirds may be locally abundant and cover a broad geographic range. However, they may have specific requirements for habitats—particularly during the breeding season—that are not abundant in the landscape and hence are threatened by land use. The Carolinian forests of southern Ontario are fragmented and consist of small populations. Although they represent the northern extension of a forest system much more widespread and abundant in the eastern United States, these remnants constitute part of Canada's characteristic biodiversity. The degree to which a species is endangered or vulnerable to extinction is very much determined by the spatial context and the relationships between range, population size, the impact of land use change, habitat, and habitat quality. Previously, habitat quality was considered in terms of a monotonically increasing scale from "low" to "high." Recent theoretical developments, however, point to a more complex landscape matrix of "sources" and "sinks." This suggests that "suitable habitat" may in fact require an intricate assemblage of patches that comprises lower-quality patches in addition to the full complement of higher-quality patches (i.e., suitable patches are needed where the populations can expand to when times are good).

It is useful to make the distinction between global and local extinctions. The former is when all populations of a species cease to exist, the latter when only those populations present in a given landscape are eliminated. Global extinctions of "flagship" species (e.g., whales) often attract widespread and public concern. Unfortunately, local extinctions are usually overlooked (Ledig 1993). "Effective" extinction can be achieved without eliminating every member of a population if, for example, population size is too small to maintain genetic variability and to ensure the maintenance of the population through time. This leads to the observation that although local diversity can be increased through management practices (e.g., introducing disturbances to promote pioneer species), this could lead to a decrease in the viability of certain local populations and hence potentially promote and contribute to the global extinction of species (see also Gilpin and Soulé 1986).

Community organization and ecosystem processes

Populations co-occur in space and time and thereby form biotic communities. How much importance should be given to community organization? Johnson and Mayeux (1992) suggested that species have been added to or removed from ecosystems in many contexts without greatly affecting ecosystem function. They proposed that the physiognomic structure (vertical and horizontal) of the vegetation is in the long term more important to ecosystem stability and resilience than taxonomic composition per se.

In terms of plant associations, we can identify both "weak" and "strong" positions. A weak position might argue, for example, that vegetation associations are largely fortuitous, either the result of stochastic events and disturbance history or due to overlapping physical environmental requirements and tolerances. This viewpoint would indicate that no great effort is required to preserve existing associations. The conservation goal then becomes more simply to ensure that all potential species remain present within a landscape.

A "strong" position would suggest that there are overriding biotic interdependencies, and that communities have a well-developed internal organization. The effects of canopy shading on regeneration, microclimate, and soil moisture, for example, are indicative of processes that stem from, and are part of, the process of community organization. An argument would be that this community organization is essential for both the presence of certain species and the maintenance of ecosystem functions. It would then follow that species and population conservation can occur only if the processes that derive from community interactions are protected. The case for strong community organization is less controversial with fauna, as they utilize plants for shelter (e.g., protection, thermoregulation) and nutrition and often develop quite specific plant-dependent habitat requirements. Animals partition available resources by various techniques, such as utilizing different components of the vertical structure of plants or foraging at different times of the day.

The notion of ecosystem stability and resilience stems from the fact that ecosystem processes persist even though individuals and populations may come and go (see Holling 1973, 1992). These processes are the result of community organization. At a landscape scale, two of the most important processes are the water and nutrient cycles. These involve complex interactions between plants, animals, climate, terrain, and the substrate. For example, in the nutrient cycle, plants generally constitute a major reservoir of nutrients in a system. The uptake of nutrients by plants counteracts the removal of nutrients by leaching and erosion processes. Soil biota provide the means by which organic material is broken down and made available for plant uptake.

Soil microflora represent an important component of biodiversity in terms of both the number of species and the roles they play in forest ecosystem processes. Soil fungi and bacteria may fix nitrogen, stimulate tree growth, regulate pathogen populations, facilitate decomposition of organic material, and influence soil structure. Chanway (1993) suggested that the maintenance of mycorrhizal diversity below the ground is necessary to ensure the biodiversity of the aboveground vegetation. He also noted that there may be guilds of tree species defined by their common association with mycorrhizal fungi.

The relationships between ecosystem processes and animal habitat are generally ill-defined owing to a lack of knowledge. Habitat can be defined as a function of ecophysiological response, as, for example, defined by the mesoscaled climatic requirements of an organism; and requirements for both nutrition and shelter. The latter two can involve the utilization of other plants and animals. Ideally, habitat models should include all three components. However, vegetation is frequently used as a surrogate. For example, it is possible to relate bird habitat to patches of extant forest types (e.g., Welsh 1993). The relative quality of a given habitat patch will depend upon whether it contains specific attributes (e.g., a required shrub density) and more general factors such as the overall site productivity. These, in turn, may be driven by basic landscape processes that determine the distribution and availability of soil moisture and nutrients. Also, the presence and persistence of any one habitat patch may depend upon various ecosystem processes generated and sustained by the broader forest system.

Disturbance regimes

Fire is a major source of disturbance in boreal forests. Fires kill some plants and create opportunities for others to grow. The fire regime therefore exerts a fundamental control on the spatial mosaics of forests' age structures (which in turn suggests that the extant age distribution of trees in "natural" forests can be used to infer fire frequencies). Boreal forests, for example, are generally younger than Pacific coast forests, largely because of differences in the fire regime.

Other phenomena also help define the natural disturbance regime. Insect infestations (budworms, caterpillars) occur in vast numbers and over large areas of the boreal system. One effect is that of accelerating the recycling of nutrients in the system. Fungi that attack the root systems of trees, resulting in premature death of the plants, are also prevalent. Fire, insects, and root diseases are therefore commonly considered the major natural agents of change in Canada's forests (Bonan and Shugart 1989).

The relative impact of human land use disturbances is the source of much controversy. In the context of forestry, one view is that timber harvesting mimics the disturbance effects of fires. Opposing this is the view that, in spatial terms, fires burn more heterogeneously than timber harvesting, and that fires often leave behind more plant material and hence nutrients. Also, it is apparent that modern society has changed the natural fire regime through specific fire suppression policies and the reforestation of extensive areas with new species mixes that have different burn patterns. It is argued that this has interrupted and will continue to redirect natural vegetation successional pathways.

Many consider insects to be pests and root fungi to be diseases, and hence these organisms are classed by some as undesirable disturbances. The opposing and increasingly accepted view is that these play an integral role in nutrient and carbon cycling within a forest ecosystem. Some forestry practices may be responsible for an increase in the likelihood of insect and root, butt, and stem fungi infestations.

Perhaps the critical questions are the extent to which land use practices have changed and are changing preindustrial disturbance regimes, and the extent to which these are affecting population viability, species distributions, vegetation associations, forest age structures, and ecosystem functions.

The role of the physical environment

As noted above, local adaptations to physical environmental conditions represent an important component of biodiversity. All plants require energy, moisture, and mineral nutrients. The spatial and temporal distributions and availability of these three primary environmental regimes (PERs) are therefore the major physical determinants of plant response—in terms of taxonomic distribution, physiognomic structure, and primary productivity. PERs also directly affect the ecophysiology of animals and, through the effects on plants, their requirements for shelter and nutrients. In addition, PERs exert a major control on the rates of basic biophysical processes (e.g., water use). Spatial distributions of PERs can often be used as predictors of biological pattern, particularly in mature ecosystems. PERs have been used, for example, to predict potential species distributions (e.g., Nix 1986; Booth 1990). Phenotypic variation among tree populations has also been correlated with climatic and soil conditions across a species' range (e.g., Rehfeldt 1990). Clearly, the physical environment is inextricably linked to all the components of biodiversity.

Spatial scale

Figure 1 illustrates how the physical environment, species and populations, human impacts and natural disturbances, and community organization and ecosystem processes can interact over a range of spatial scales. It can be argued that all components operate and can (at least in some fashion) be discerned at all scales, thereby suggesting the following:

1. At increasingly finer scales, more factors can be incorporated to refine estimates of physical environmental processes; also, gradients in the distribution of energy, moisture, and mineral nutrients vary spatially.

2. Species and population distributions can cross all scales.

3. Biological patterns emerge at higher levels in the spatial hierarchy that are not apparent at lower levels.

4. Ecosystem processes transcend scales, depending upon the "steepness" of environmental variables (e.g., the degree to which mesoscaled climate changes in relation to horizontal distance) and the distribution patterns of the populations involved.

5. The ecological importance of disturbance depends upon the scale of community organization being affected.

The (perhaps obvious) implication is that more than one unit of biological and spatial analysis is needed, because at any one of the four scales shown in Figure 1 it is possible to focus on species, populations, habitat/environmental relations, community organization, and ecosystem processes. A comprehensive set of indicators is required that samples the various components of biodiversity and the impinging processes, as expressed at different scales.

Biological organization is often viewed as a nested hierarchy, such as cell → organism → population → community → ecosystem → biome. Also, we can recognize a nested hierarchy of spatial units, such as site → landscape → region → globe. There is not necessarily, however, a direct correspondence between these two nested hierarchies (see Allen and Hoekstra 1990). For example, a soil fungus's ecosystem might be smaller than a plant's community; the home range of a bird population can be larger than the areal extent of a landscape; a species' distribution can cross biomes; populations can form part of more than one community. Organisms also vary enormously in their degree of

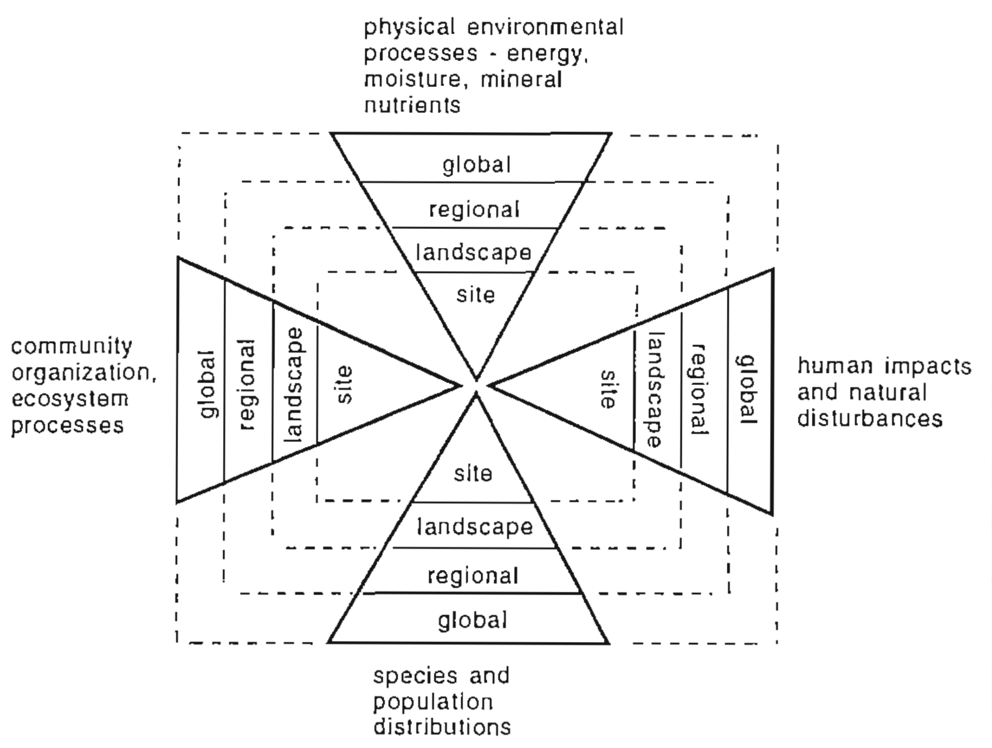

Figure 1. Components of biodiversity, impinging processes, and scale. All components and processes can transcend all scales.

mobility. Although individual plants tend to be immobile, even plant species migrate, given sufficient time.

The point is that the spatial distribution of biological organization at various scales may be best represented by a non-nested hierarchy. If a nested set of spatial units is used, then the expressions of biodiversity captured at the broader scale may not capture biodiversity expressed at a finer scale. However, if a nested set of spatial units is not used, then there is no longer a simple method of linking across scales.

Options for biodiversity indicators

Units of analysis based on species

Species diversity indices

Species diversity indices (SDIs) are based on quantitative measures of species richness, abundance/dominance, and evenness. These utilize information theory and other measures that make no a priori assumptions about distributions (Samson and Knopf 1982). Examples include Simpson's Index (Simpson 1949) and the Shannon Weaver Index (Peet 1974; see also Pielou 1966).

Indicator species

It is not feasible to comprehensively study all populations of all species. It is possible, however, to examine selected "indicator species" using various criteria:

- economically important species, e.g., moose;
- culturally important species, e.g., sweet grass;
- guild representatives, e.g., one species to represent a number of ground-breeding migratory forest songbirds;
- top-of-the-food-chain species, e.g., large owls;
- species with large home ranges, e.g., woodland caribou;
- flagship species (i.e., species with popular appeal), e.g., whales;
- keystone species (i.e., species that play a critical role in the maintenance of ecosystem processes), e.g., soil fungi; and
- rare, threatened, endangered species, e.g., pine marten.

There are also strong arguments against indicator species (see Landres et al. 1988), including the following:

1. Each taxon has its own *umwelt*, or unique set of biophysical requirements and responses (von Uexkull and Kriszat 1934).

2. Predators may be dependent upon prey, but the reverse is not true: i.e., there is a need to be cognizant of the interdependencies between species that may not be accounted for by a nested hierarchy.

3. There is a current lack of autecological and synecological knowledge.

4. Species can come and go, yet ecosystem services can still be maintained.

Nonetheless, much of the public discussion on biodiversity conservation has focused on indicator species, in particular rare or endangered species (e.g., spotted owl in the Pacific Northwest or the red-cockaded woodpecker in the southern United States) or commercially important species (e.g., moose in northern Ontario). In addition, landscapes and ecosystems that have a relatively high level of species diversity or relatively large populations of indicator species have also attracted attention.

Units of analysis based on intraspecies diversity

It is possible to examine, on a species-by-species basis, the extent to which populations can be distinguished owing to local adaptations. One method is to collect seed from sample locations and study phenotypic variation in plant growth characteristics under controlled conditions. Variation in phenotypes between populations can then be examined to see if correlations exist with environmental conditions at the sites (e.g., Rehfeldt 1990). If local variations are significant, then the results could be used to identify populations that warrant conservation.

There are various techniques that can be employed to measure the actual or relative genetic difference between populations in terms of heterozygosity—allelic and isoenzyme DNA-based measures (e.g., Jain 1983; Riggs 1990). But how can genetic diversity measures be interpreted—for example, to what extent does the difference between populations in genetic diversity per se constitute a component of biodiversity that should be conserved?

It is also possible to undertake population viability analysis (PVA) simulations on selected populations of a single species. Several computer-based models exist for such applications—e.g., ALEX (Possingham et al. 1993) and VORTEX (Lindenmayer et al. 1993). The identification and utilization of suitable habitat patches in a landscape become the focal point for these analyses in conjunction with knowledge of the life history of the species. Spatial data about forest fragmentation are also an important input, as the size and spatial configuration of the habitat patches can affect viability. Choices about the target species for PVA have the same caveats as mentioned above for indicator species.

Units of analysis based on community organization and ecosystem processes

Advocates of a "strong" view of community organization would suggest indicators based on levels of biological organization above that of populations and species. Perhaps the simplest way to capture this component of diversity is to focus on extant patterns of biotic associations as indicators of biotic-environmental relations. These can be defined using a variety of criteria, including:

- plant floristic associations (e.g., based on dominant canopy species or commonly co-occurring assemblages of overstory and understory plants);
- vegetation physiognomic structure (e.g., life forms, canopy height/density, vertical structure such as density of shrub and herb layers); and
- potential habitats of indicator species or guilds (where habitat is a function of physical environment, shelter, and nutrient requirements).

This argument can be extended to the issue of biophysical patterns and processes that emerge at a regional spatial scale. Ecological regionalizations (e.g., ecological land classification in Canada [Hills 1961; Wiken et al. 1992]; environmental domain analysis in Australia [Mackey et al. 1989]) aim to capture these broader-scaled patterns and processes. Ideally, these analyses would be suitable for addressing widespread calls for a representative system of protected reserves to be established. Many international and regional governments support the notion that 12% of the Earth's terrestrial systems should be protected within a reserve network. An argument in favor of a representative reserve system is that it serves as a "coarse filter" for the maintenance of broader-scaled patterns and processes (Hunter et al. 1988).

A critical issue in applying representativeness as an indicator is the selection of criteria used to define the system boundaries. Options include boundaries based on:

- physical gradients (e.g., the primary environmental regimes);
- gradients in vegetation physiognomic structure (e.g., distinguishing grasslands–woodlands–deciduous forests–boreal forests–tundra);
- actual or potential species/habitat distributions;
- the spatial variation in phenotypic variation across populations;
- actual or potential mature vegetation associations and environmental relations; and
- measures of biophysical process rates (e.g., foliage production, plant water use).

Assessments of representativeness can clearly be applied to units other than regionalizations. For example, it is logical to consider reserving a representative sample of "old growth" for a given forest type (e.g., percent area coverage within an ecoregion).

Even if 12% of land is reserved, this would still leave 88% remaining. It can be argued that the conservation of biodiversity will be affected more by what happens outside reserve networks than by what happens within. This is especially so in a country like Canada, which is dominated by natural landscapes and whose economy is currently so linked to the viability of natural resources. The use of a regionalization to assess representativeness does not necessarily help biodiversity evaluation on the remaining 88% and may in fact breed a sense of complacency. However, additional uses of regionalizations can be envisaged, including:

- spatial stratifications for evaluating the significance of species diversity or other indices; and
- characterizing spatial variation in the primary environmental regimes, and hence the potential for local adaptations (but rather than focusing on a particular taxon's response, the regionalizations could be used to capture major physical gradients that are indicative of significant clusterings of ecological gradients).

Note that land-based regionalization does not necessarily address aquatic ecosystem biodiversity!

Indices of disturbance and change

The disturbance regime is multidimensional and can be defined in terms of intensity, duration, frequency, extent, and the causal agent (e.g., land use, fire) (Hopkins 1990). These variables all affect the ecological impact of a disturbance on biodiversity. Hence, simply obtaining spatial information about extant disturbance regimes is complicated.

Remotely sensed data provide a means to gain spatially extended data on the extent of forest fragmentation. Various statistics (e.g., based on fractal theory; see Forman 1986; Moore et al. 1993) can be calculated to give indicators of extant landscape heterogeneity. The problem remains, however, of interpretation—for example, do forest fragmentation and the spatial configuration of patches have any meaning aside from their effect on a given species' habitat requirements, an individual organism's fitness, or a particular population's viability?

Disturbances do not necessarily result in the loss of forest cover per se. Rather, there is often a continuum of effects. Lesslie et al. (1988) discussed a computer-based method for the inventory of wilderness quality based on this continuum concept. Wilderness quality was calculated as a continuous function of four indicators, namely distance from access, distance from settlement, apparent naturalness (e.g., the density of uninhabited human structures), and biophysical naturalness. The latter is an attempt to map the ecological impact of land use history.

The above discussion has focused on units of analysis based on extant or potential biophysical patterns. It is also clear that many of the indicators suggested for characterizing the biodiversity of a landscape are equally applicable for monitoring the dynamics of environmental change through repeated measurement. However, another set of indicators can be envisaged that directly measures, for example, changes in the flux of moisture, nutrients, and energy through a forest ecosystem. These would require a time series of observations such that the effects of land use on forest processes can be monitored. Some remotely sensed data sources may be useful. However, they would still require ground-based instruments for calibration.

The distribution, abundance, and viability of animal populations are other ecosystem dynamics that are amenable to time series analysis based on ground-based monitoring stations; are populations in decline, stable, or rising? Once again, though, not all species can be examined, and criteria are needed for selecting one target species over another.

Logistic issues

In addition to scientific considerations, the availability of data, cost of measurement, and ease of application must also be considered in selecting biodiversity indicators. In this section, it is also convenient to examine problems associated with assessing the impact of accumulated effects.

The ecological tyranny of small decisions

The point made in the quotation by Perrings et al. (1992) above about the "billions of independent decisions" that are directly responsible for most of the world's biodiversity loss is critical to the assessment of the status of biodiversity. This has been referred to as the tyranny of small decisions (Kahn 1966). In the market economy, billions of people are continually expressing personal preferences that have an impact on the planet's biodiversity. Independently, each decision likely has an insignificant impact. In toto, however, the effects may be significant and may be in conflict with the social good. Markets do provide some feedback about the impact of the scale of economic activity. For example, all else remaining the same, as a good becomes scarce, its relative price will rise, inducing substitution, less consumption, and even technological innovation. However, there are not necessarily feedback mechanisms for unpriced goods or services, such as the noncommercial components of biodiversity.

An analogy can be drawn with the Great Wall of China. The wall in its entirety consists of millions of bricks, any one of which is relatively worthless. A single brick can be removed without having much effect on the total value of the wall. But how many bricks can be removed before we consider the wall damaged? How many bricks can be removed before there is no longer a wall?

The tyranny of small decisions also confounds the development of meaningful biodiversity indicators. Forests are continually affected by human-induced disturbance (e.g., global climate change, pollutants, conversion of forested land to other land uses, the impact of timber harvesting). But what are the cumulative effects on different components of the forest biodiversity? For example, northern Ontario provides breeding habitat for some 75 species of migratory birds. These species have different habitat requirements (Welsh 1987). How does the patchwork of timber harvesting that has occurred in northern Ontario over the last 30 years affect the long-term viability of these species, and how does that vary spatially? This leads to the topic of threshold values—i.e., how do we determine that an impact on biodiversity is significant?

Evaluating the significance of recent land use activities is further compounded by longer-term perturbations. For example, analyses based on arctic ice cores showed that the climate of the last 10 000 years has been atypically stable compared with the last 250 000 years (Nielsen 1993). As yet, no definitive causal hypotheses have been proposed. It is possible that human-induced environmental change could interact with whatever is driving the longer-term climatic oscillations, resulting in accelerated global perturbations—how many cracks can appear before the wall collapses?

The determination of threshold values will clearly become the focus of public debate; what is required first, however, are measures of the cumulative impact of mutually independent actions.

Source data for indicators

Indicators must be based on data and information that are georeferenced—i.e., tied to localities on the Earth's surface. However, we do not know where everything is, and we do not know how everything is related. Also, it is difficult to map processes. Given the potential set of indicators noted above, what types of attribute data are required, and what is the availability of source data?

Although more complex levels of community organization may be difficult to pin down to a spatial scale, populations are more readily defined within a landscape. However, even here there are considerable limits to the resolution of data. Except in a very few cases, it is generally impossible to locate all populations. In fact, information about the extant spatial distribution of plants and animals is surprisingly poor for land use decision making. The spatial distribution of biota is usually modeled rather than directly observed. For example, traditional vegetation surveys record observations at a small number of irregularly scattered sites. The problem becomes how to extend these data to cover the entire landscape or region. This spatial extension problem applies to a wide range of environmental variables, including soil data, wildlife surveys, climatic averages derived from weather stations, topographic surveys, measurements of water flow, sediment yield, and chemical and biological oxygen demand. The traditional solution to this problem is through mapping based on air photo interpretation—i.e., using assumptions of covariance between survey plots and visually discerned patterns on the imagery.

In contrast to point data, remotely sensed (R/S) spectral/emittance data (especially satellite-borne sensors such as Landsat TM, SPOT, ERS, and Radarsat) are delivered in spatially distributed formats—i.e., there is a value for each pixel across the entire image. However, these values need to be interpreted—there is not necessarily a direct correspondence between the spectral values and the target land cover features.

Developments over the last 10 years have transformed our ability to model the spatial and temporal distributions of energy, moisture, and mineral nutrients (i.e., the primary environmental regimes). For example, new methods enable spatially reliable estimates of long-term mean monthly climate to be generated at any location with acceptable standard errors (see Hutchinson 1987). Compound terrain indices generated from digital elevation models enable spatially distributed models of catchment hydrology to be calibrated and applied across entire landscapes. These enable the spatial prediction of soil attributes and processes that relate to water flow (e.g., Moore et al. 1991). Some of these new methods are being adopted in Canada (e.g., see Mackey and McKenney 1994).

New methods are being developed for the spatial analysis and prediction of biological and ecological phenomena. These are based on integrating point observations, remotely sensed data, spatially extended simulation models of physical environmental attributes, and various forms of spatial statistics. Applications include the capability to predict spatially the probability of occurrence of biota based on correlations with physical environmental variables (e.g., Mackey 1993) and more sophisticated methods of deriving remote sensing classifications and analyses that utilize ground-based land information (e.g., Brown et al. 1993; Lees and Ritman 1994).

Generally, point data can be spatially extended if their distributions can be related to other variables for which spatial data are available. Geographic information systems (GIS) and environmental modeling technologies therefore provide the means to integrate spatially both existing and new data sources and to examine in a statistically robust fashion the environmental response of biota across scales.

Summary and issues affecting selection of indicators

The development of a comprehensive set of useful biodiversity indicators involves an understanding and synthesis of many complicated scientific issues. For indicators to be useful, they should constitute a feedback mechanism in the decision-making process. There needs to be a link between the observed change in biodiversity and the causal agent. This information can then be used by resource managers, other decision makers, and the public. The development of biodiversity indicators is a major step towards assessing the net value to society of biodiversity conservation (although it is worth noting that indicators are only one, albeit a critical, component of a well-balanced program for the conservation of biodiversity; see Thompson and Welsh 1993). This paper reviewed the basic components of biodiversity, from species and populations to community organization and ecosystem processes. Other important issues included the role of disturbance, the physical environment, scale, and data sources.

"Biodiversity" is more than "species diversity." There are at least three complicating factors:

1. Many components of biodiversity result from interactions between biota—e.g., the vertical structure in vegetation communities is partly the result of interactions between canopy and understory plants.

2. Biodiversity is manifested and can therefore be examined over at least four scales (none of which is mutually exclusive; see Figure 1).

3. Even within a relatively species-poor country such as Canada, there are tens of thousands of species, especially when soil microfauna and microflora are considered. It is theoretically possible that each species has a unique *umwelt*.

It is unlikely that one index or a small number of indices will suffice. However, the enormity and urgency of the task and the limited resources available demand that a finite set of indicators be defined. The first requirement is the development of indices to establish a baseline or characteristic biodiversity.

Indices will be required that operate at a selection of space/time scales: e.g., the diversity and abundance of ground cover species in a landscape can be sampled using a network of ~100-m^2 plots; the distribution of patches of forest types requires fine-grained analysis but over an entire landscape of, say, 900 km^2; analysis of forest songbird habitat requirements may require the collection and analysis of some detailed observations over 3–5 years or longer from 1-km^2 plots scattered over an entire region.

A second set of indices would be needed to describe the extent to which anthropogenic activities are (or are not) resulting in biological impoverishment. There would be a subset of indices that could be used both to characterize biodiversity and to monitor change through time. The development of indices requires a combination of point and spatially extended data. Simulation models will also have a role to play. The availability of suitable source data and the cost associated with acquiring new data will be limiting factors.

This paper has briefly discussed a number of contentious issues that may affect the selection of indicators. These issues are summarized by the following questions:

1. Do species diversity indices in themselves have any utility?

2. Should indicator species be used? If so,
   - what are the criteria for their selection and limitations for their use?
   - should point observations or data derived from spatially modeled potential distributions/habitats be used?

3. How can local adaptations and genetic variation be measured and inventoried through space and time?

4. In what circumstances are floristic/structural associations based on mature vegetation response meaningful/useful?

5. What uses can be made of environmental regionalizations? How should system boundaries be defined?

6. Are nested spatial hierarchies useful? If not, then how do we relate system boundaries across scales?

7. It appears that the significance of many indices cannot be determined unilaterally but needs data about other indices to provide context—e.g., remote sensing enables extant land cover patterns to be spatially inventoried, but what additional data are needed to interpret the significance of forest fragmentation? Which indices require other data for context, and how can they be combined in a meaningful way?

8. To what extent is information about land use history important?

9. Is it possible or necessary to distinguish the impacts of human-caused disturbances from natural disturbance regimes?

10. How adequate are existing data bases? To what extent can existing data be analyzed and modeled to generate the required information?

11. For which indicators are new, point-specific monitoring programs needed? Should the focus be on indicator species or selected components of ecosystem processes? How many sites are required, and where?

12. Which indices require more research before they can be implemented?

13. What resources are required to implement the preferred indicators?

Given the scope of possible indicators suggested here, we suggest that they may be categorized as either species-based or system-based indicators. The species-based category includes the use of endangered or flagship species as well as indicators of intraspecies genetic variation. The system-based category is intended to cover measures of forest structure and composition, the use of vegetation associations and ecological regionalizations, and measures of soil erosion or nutrient loss.

Species can be used as indicators in at least three ways. First, a species can be used as an indicator where the objective is to ensure the preservation of that species. In these cases, it is simply "good fortune" if this results in the preservation of other species. Second, the species can be used as a surrogate for other species with correlated life histories or habitat requirements. Here, the objective is to focus on one species with the aim of protecting many others. Third, a species can be used to assay the condition of the forest ecosystem. For example, the distribution and abundance of some plants (r-strategist) could indicate the extent to which a system is recovering from a perturbation. Similarly, the presence of certain soil fauna may indicate the impact of a forestry operation on the soil profile. In terms of our classification, the first and second are species-based, whereas the third is system-based. There is another class of indicators that are concerned with the overall "health" of the forest ecosystem and are not related to measures of a single species—e.g., landscape-scaled measures of forest cover/fragmentation, or the changes in the vertical structure of a forest stand over time. These clearly fall within our system-based category. Also, a system-based measure could be used to indicate the status of a species.

Like many classifications, there is considerable overlap. For example, focusing on a species' habitat requires data about the vegetation community's composition, structure, and productivity—attributes that can be addressed by system-based indicators. Similarly, species diversity indicators give a picture of a system's characteristic composition but are based on individual species distributions and abundances.

Conclusions

The primary purpose of raising the various issues in this paper was to provide a context for the workshop discussion. It is important to be aware of the limitations in using a given indicator and of the potential for misinterpretation. The complexity of the subject also demonstrates that certain issues are unlikely to be resolved in the short term. Categorizing indicators into either species- or system-based groups provides a convenient theme for structuring discussion on indicators. We believe that some type of baseline must be established against which change can be measured. This requires that the characteristic diversity of a place be defined. Ultimately, we must deal with what is happening in the landscape—the plants and animals and processes that are in place—together with the impact of land uses such as forestry.

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Biodiversity and Canadian Forests

Richard A. Sims and Paul A. Addison

Introduction

This paper provides some general background on the extent and nature of Canada's forests and some contexts for the examination of biodiversity issues in relation to Canadian forests. Some key points are made regarding current and future forestry practices in relation to biodiversity conservation and the potential for measurement/monitoring thereof.

Towards a working definition of "forest biodiversity"

It would be useful to have a precise definition of the term "forest biodiversity." One working definition of biodiversity is "the variety of life in all of its forms, levels and combinations, and including ecosystem diversity, species diversity and genetic diversity" (McNeely et al. 1990; U.S. National Research Council 1992). The operating word in this definition is "variety" and the attendant implications on how it may be measured, estimated or valued, and then interpreted or applied for various purposes.

In overview, "biodiversity" defies a simple definition primarily because it is a complex of finer-leveled issues (e.g., see Hunter 1990; Millar et al. 1990; U.S. National Research Council 1992; Duinker 1993; Ledig 1993; Ontario Forest Policy Panel 1993; Woodley 1993; Mackey et al., these proceedings), each of which must be addressed independently to some degree. In general, authors dealing with the topic either concentrate upon one of the many finer-leveled issues (e.g., species diversity, genetic diversity, landscape diversity) or attempt to define the range of types of biodiversity that occur (e.g., see Noss 1990). To date, there is little guidance available on how we may proceed with the integration of the component parts into an acceptable, scientifically valid, and truly comprehensive scheme (i.e., one that weighs and balances components).

We need acceptable and common working definitions of basic terms like "forest," "ecosystem," and other terms that are frequently used to help give context to the biodiversity issue (Hunter 1990; U.S. National Research Council 1992; Thomas 1993). Terms like "forest" are not easily handled, because the term is defined according to the perceptions or requirements of a very diverse user base. The public's definition of the forest is broad, ranging from a perspective that is largely visual to one that is emotionally or spiritually charged. To the practising forester, "forest" may have a very specific scientific definition, usually taking into account the tree species composition, age class, density, and productivity functions. For the ecologist, forest site classifications provide finer details of ecosystem conditions, and the ecologist may define forests in even more comprehensive ways, based upon soil features, physiognomy, vegetation communities, and moisture/nutrient regimes.

Most working definitions of biodiversity imply that it is chiefly a scientific preoccupation. However, from all that is known about the current anathema with the issue, it also involves the consideration of a wide range of political, ethical, economic, and social concerns. Because of this, certain perspectives that arise about the priorities for research and development as related to biodiversity are thus frequently in apparent conflict.

For example, out of the scientific versus political debate over the development of indicators that may be used to measure or monitor biodiversity conservation, the following question (among many others) arises: is the primary requirement a set of accurate, scientifically detailed, and strongly defensible measures, or is the primary requirement a set of "indices" that may be scientifically weaker but are more readily understood or appreciated by the general public? In other words, should the collective scientific efforts at this point be focused more upon the quick rallying of public support or upon the longer-term, painstaking process of documenting biodiversity shifts and problems? In all probability, we cannot afford to focus upon just one of these perspectives of the biodiversity issue, and the scientific community must instead be organized to address such multiple considerations at the same time. Of all the sciences that must be brought to bear on the biodiversity issue at the current time, perhaps the science that we know least about, and are least likely to incorporate successfully into a scientific model, is political science.

Portraying forest biodiversity within a schematic framework

One method of conceptualizing biodiversity conservation issues is to use a "focal elements" approach that directs attention to functional relationships within a hierarchy of geographic scales (e.g., see Noss 1990; Neilson 1993). Schematically, a three-dimensional matrix can be used to characterize the three main gradients that interact to define biodiversity for different "elements" or components—i.e., the biological, geographic, and ecological continua (e.g., see Thomas 1993; Figure 1). This may be more difficult conceptually, but, in some senses, it is more representative in the way it requires consideration of the "gradients" involved. Figure 1 places "conservation of biodiversity" along three interconnected axes, which represent three primary, ecologically related dimensions: temporal, spatial, and biological. An additional focus on the "effects of forest operations" should be included within this conceptual framework when considering forest biodiversity issues. To effectively deal with biodiversity conservation over time in forested areas, the actions and reactions of anthropogenic disturbances across all three gradients must be determined directly.

Regardless of the framework, it is important to have a clear idea of the nature of the indicators that are chosen to calibrate or gauge the biodiversity conservation effort in toto. To identify "biodiversity indicators," we first need to undertake the following steps:

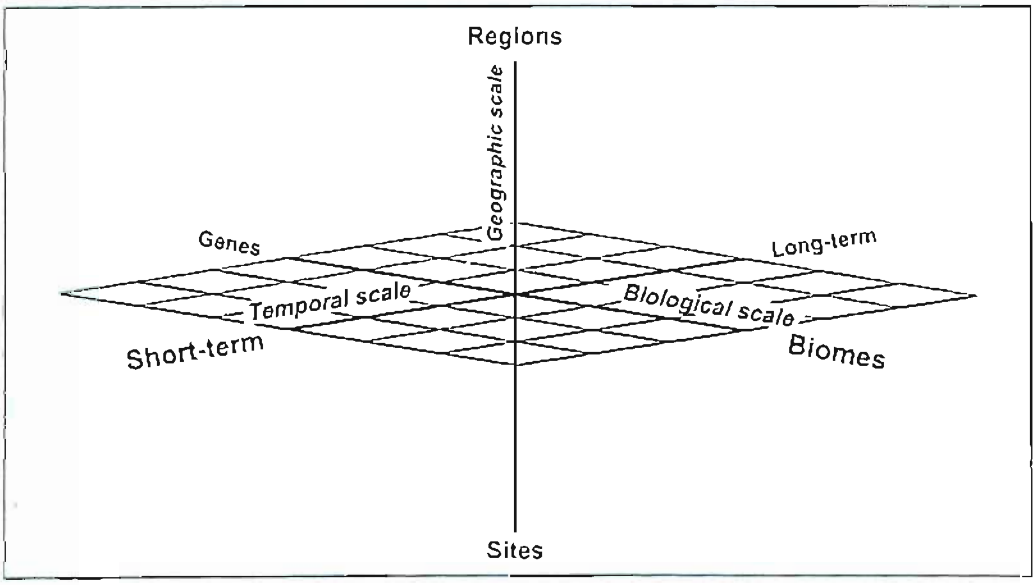

Figure 1. The three main gradients (biological, geographic, and temporal) that interact to define biodiversity.
Source: After Salwasser (1993).

- determine the kinds and numbers of indicators that are required, including direct, indirect, surrogate, and compound indicators, as well as measures not of biodiversity but of the effects that may impinge upon it (i.e., such indicators might be referred to as "second order indirect");
- clarify and document the elements of biodiversity that these indicators will represent or measure (e.g., monitoring can range from simple identification to very detailed statistical examination of fluctuations or shifts due to, for example, forest management practices);
- identify the tolerances and ranges of variability that would be required or accepted around each of these indicators, as well as any "compound" effects that might arise should certain indicators be grouped or lumped for some purposes; and
- demonstrate the nature and dimension of any "random effects" that may arise in measurement or estimation of any indicator (i.e., what are the error sources, the unknowns, and the magnitudes of any random fluctuations that must be "factored out" when determining a component of biodiversity).

The purpose of this workshop is to initiate discussion about the first step listed above—the types of indicators that could be identified as having value for biodiversity measurement and monitoring within Canadian forests. Addressing this first step alone is a formidable task, and one that must be done using a logical, scientifically based approach.

Canada's forest land base

Canada is home to about 10% (416 million hectares) of the world's forested land. In terms of cubic volume, Canada has 16% of the world's softwood (conifer) volume and 3% of the world's hardwood volume; in total, this represents some 15 billion cubic metres of wood fiber (Forestry Canada 1992). The forest industry in Canada is extremely important; Canada is the single largest wood products exporter in the world and produces 31% of the world's newsprint, 12% of wood products, and 7% of all paper and paperboard products (Canadian Pulp and Paper Association 1992).

Just over half of the forested land in Canada is considered "commercial" by existing definitions of tree size and potential productivity (Table 1). An area of about 112 million hectares, or about one-quarter of the total, is considered to be under current

Table 1. An overview of Canada's forest land.

Forest type	Area (million hectares)
Heritage forests	22.8
Commercial forests	236.7
Managed forests	*112*
Unallocated forests	*100*
Protected forests	*24*
Open forests	156.6
Total forest land	416.1

Source: After Canadian Pulp and Paper Association (1992); Forestry Canada (1992).

management for the forest products industry. About 0.5% of Canada's total forest lands are harvested annually (Forestry Canada 1992). Forest management is primarily a provincial jurisdiction; 94% of the forest is "Crown land," although the majority of commercially important areas are turned over in licences to forest companies for harvest and reforestation. The remaining 6% of Canada's forests are held by some 425 000 private landowners (Forestry Canada 1992).

Although there is much pristine forest land in Canada, there are significant industrial pressures on the resource from coast to coast to coast. This has resulted in some local wood supply shortages and a growing number of geographic locations where there are environmental and integrated management concerns (Kimmins 1992; Booth et al. 1993).

Taxonomic diversity within Canada's forests

Taxonomic diversity (or, in one sense, species richness) refers to a simple accounting of the taxonomic holdings of a geographic area. Currently, some 71 000 microorganisms, plants, and animals, representing in total some 70 taxonomic phyla, are known and documented in Canada (Mosquin and Whiting 1992; Table 2). However, relative to its immense size, Canada can be considered to be "species poor." The total number of species in Canada still represents only about 5.1% of the 1.435 million described species of the world (McNeely et al. 1990). Canada is estimated to have 194 species of mammals or about 31 per 10 000 km^2 (Mosquin and Whiting 1992), a density that is considerably lower than the 38.8 per 10 000 km^2 average for temperate countries of the world, and far lower than the 79.5 per 10 000 km^2 average for tropical countries (Reid and Miller 1989).

Table 2. Summary of the taxonomic diversity of Canada.

Kingdoms and major subdivisions	Est. no. of Canadian species reported to date	Est. no. of Canadian species still unreported	Canadian reported species as % of known world species[a]
Virus	200	150 000	
Bacteria	2 400	20 800	51.0?
Algae	5 303	1 980	20.0?
Fungi	11 310	5 155	0.75
Plantae			
Bryophyta	965	50	6.0
Ferns/fern allies	141	11	1.2
Vascular	3 898	75	1.8
Protozoa	1 000	1 000	3.2?
Animalia			
Mollusca	1 400	135	2.8
Annelida	982	670	8.2
Insecta	29 913	24 653	0.1
Chordata	1 911	830	?
Mammalia	194	0?	?

[a] "?" indicates incomplete data.
Source: Mosquin and Whiting (1992).

It has been estimated that the potential number of species in Canada, including undescribed and currently unknown organisms from all phyla, and including viruses, may be 300 000. It is believed that about two-thirds of these would be associated with forests in Canada (Forestry Canada 1992; Mosquin and Whiting 1992).

Endemism is considered important when describing the biodiversity of a nation. Relatively few species are endemic to Canada (Table 3), and estimates for potential endemism range from 1 to 5% (Mosquin and Whiting 1992). These low numbers are due to several factors, including:

- the net effects of relatively recent glaciation (i.e., glacial ice retreated during about 10 000–8000 years BP over much of Canada);
- the northern clime, which restricts rates of speciation, genetic migration, and other processes such as ecological adaptation and interaction/function; and
- the extension of many species into other nations (e.g., many species that occur in Canada are circumboreal, circumpolar, or panarctic species) (Schueler and McAllister 1991).

Table 3. Species endemism in selected taxonomic groups.

Taxonomic group	No. of native species	No. of endemic species	Endemic species as % of native species
Vascular plants	3269	45	1.4
Freshwater molluscs	171	4	2.3
Freshwater fishes	177	10	5.6
Amphibians	40	0	0
Reptiles	41	0	0
Birds	426	0	0

Source: Mosquin and Whiting (1992).

Of the approximately 131 tree species that occur in Canada, there are about 50 of commercial concern. Approximately 36 of these species are currently planted in reforestation programs across the country (Forestry Canada 1992). Tree species are obviously not evenly dispersed (Schueler and McAllister 1991). Numbers are highest in southern Ontario and southwestern British Columbia (i.e., close to Appalachian and west coast glacial refugia) (Figure 2). South to north gradients across the country show the general decreases in numbers that would be expected with increasing latitude. A set of curves similar to those shown in Figure 2 would be expected if this same procedure were undertaken for the group of all known vascular species in Canada. The limit imposed by climatic extremes is also noteworthy: the isotherm for winter maxima below -40°C delineates the approximate northern limit for deciduous tree species (Schueler and McAllister 1991).

Regarding soil fauna and boreal forests, species diversity is poorly known, let alone the details of interactions or the nonrandomness effects that are at work (Marshall 1993). In some preliminary examinations of forest floors in unmanaged mixed-wood stands in northwestern Ontario, densities of soil-dwelling Collembola range up to 90 700/m^2 and include some 40 species; additionally, up to 200 000 mites/m^2 have been recorded (J. Addison, Canadian Forest Service, Forest Pest Management Institute, pers. commun.). In rich sites in coastal British Columbia, soil fauna numbers of over a million individuals and hundreds of species have been recorded (Marshall 1993). In general, even for the larger annelids (earthworms), patterns of abundance and species distributions within various ecosystems are not understood at all for Canadian forests. Currently, we are unable to make predictions about when, where, and how these organisms make their habitat selections, even though they are recognized as playing a critical role in forest humus form development, decompositional processes, soil aeration and permeability, forest site productivity, and within-ecosystem nutrient partitioning and cycling.

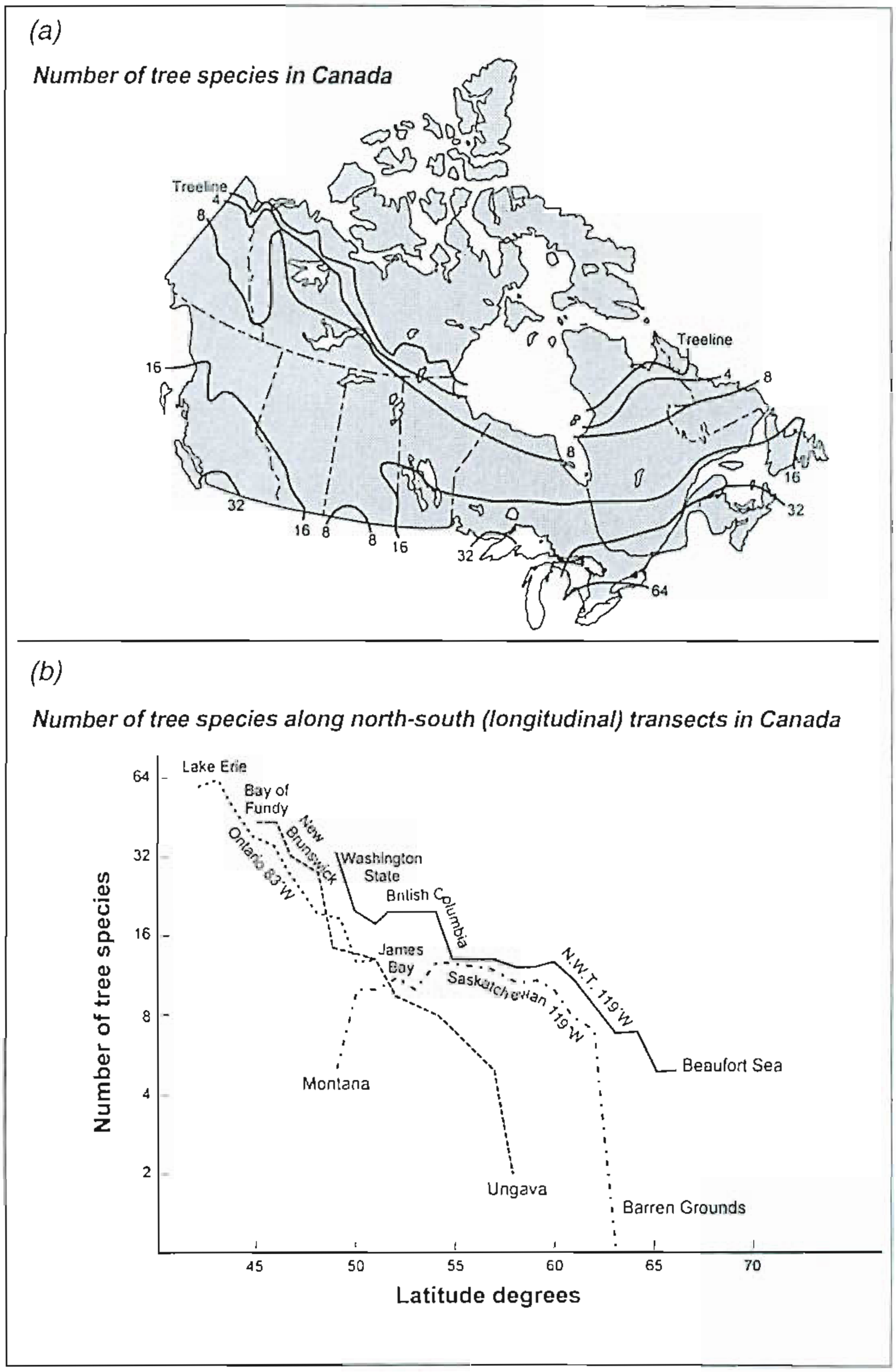

Figure 2. Generalized distributions of numbers of tree species in Canada (a), and the number of tree species along north–south (longitudinal) transects in Canada (b).
Source: Schueler and McAllister (1991).

Furthermore, there is wide genetic adaptation by many species in Canada; many species show broad ecological amplitudes and huge geographic ranges (e.g., Mosquin and Whiting 1992; McAllister 1993). Across Canada, perhaps the greatest threat is to the genetic range of adaptations that exist within species; that is, although biodiversity is certainly threatened by the loss of species in Canada, it is perhaps of greater concern that we are losing populations in the "great unseen wave of extinctions" (Ledig 1993).

However, what is far more important than the distribution of numbers of taxa is the functional interactions of organisms by dozens of ecological processes such as parasitism, nutrient transport, mineralization, fermentation, and locomotion (Figure 3). We know, for example, very little about the web of symbiotic and parasitic interactions with insects that exist for the nearly 4000 vascular species found in Canadian forests.

Forest depletions and biodiversity in Canada

The components of forest mortality and disturbance vary widely across the forest regions in Canada (Figure 4). In the Eastern Boreal, the main factor was insect kill

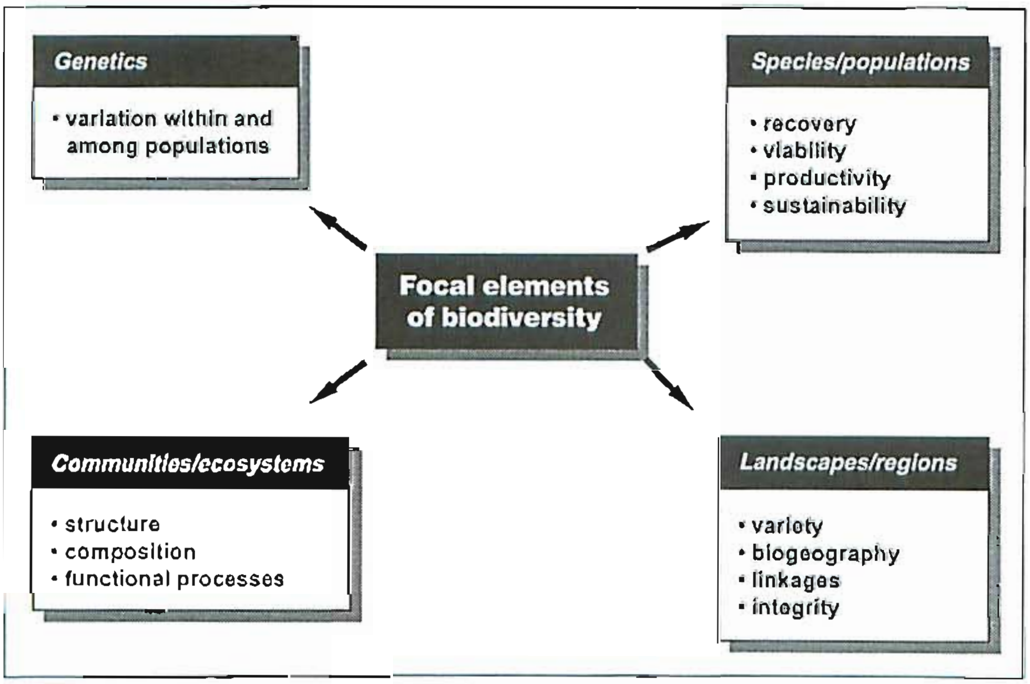

Figure 3. Linkages of functional interactions of ecological processes as a basis for ordering the study of biodiversity conservation; the definition of "focal elements" of biodiversity based on functional components at the genetic, species, community/ecosystem, and landscape/regional levels of resolution.
Source: After Salwasser (1993).

(35% of disturbance), followed by harvesting (32%). In the Great Lakes–St. Lawrence region, more than 66% of the area disturbed was depleted by pests, whereas almost 34% resulted from harvesting. On the B.C. coast, 97% of disturbance was due to logging (Forestry Canada 1992).

On average, there are 7000–12 000 reported forest fires in Canada each year, although some years have many more fires than others (Canadian Pulp and Paper Association 1992). In 1989, a particularly "bad" fire year, 7.5 million hectares burned, which is equivalent to about eight times the average annual harvest level. Normally, the area burned approximately equals the area harvested. Fire is a natural part of the ecological cycle in the boreal forest of Canada and typically controls and characterizes the natural patterns of landscape diversity (Suffling et al. 1988). From an ecological perspective, it is a losing battle to exclude natural fire cycles in such environments. Fire suppression also changes the nature of the forest age structure and tree composition over time. In spite of this, about $300 million each year is spent directly on fire suppression across the country (to this, add direct losses due to the fires that do occur, plus the costs of reforestation and salvages on burns, to obtain a more accurate estimate of the "net dollar cost" of forest fires) (Canadian Pulp and Paper Association 1992).

Timber "losses" also occur as a result of insects and diseases. In general, the amount lost is approximately equal to the area harvested (Forestry Canada 1992). Most pests follow standard oscillations and infestation patterns, and, in spite of much research and testing, the majority of suppression and control attempts are, in the longer run, unsuccessful.

Various forms of clearcuts, including block, strip, and large pattern cuts, still account for 86% of all harvesting in Canada (Table 4) (Canadian Pulp and Paper Association 1992; Forestry Canada 1992). Selection cuts are still relatively rare, accounting for only about 120 000 ha of harvested forest land annually. Such alternative and less invasive forms of harvest are becoming more widespread, particularly in second-growth (previously cut) stands in some parts of Canada.

The type of harvesting equipment used affects the nature of the environmental effects that may result. Mechanized full tree harvesting systems are widely used in some parts of Canada; these operations are fast, are cost-effective, and remove the entire tree from the stand. They use large machines that have the capacity to "muck up" and

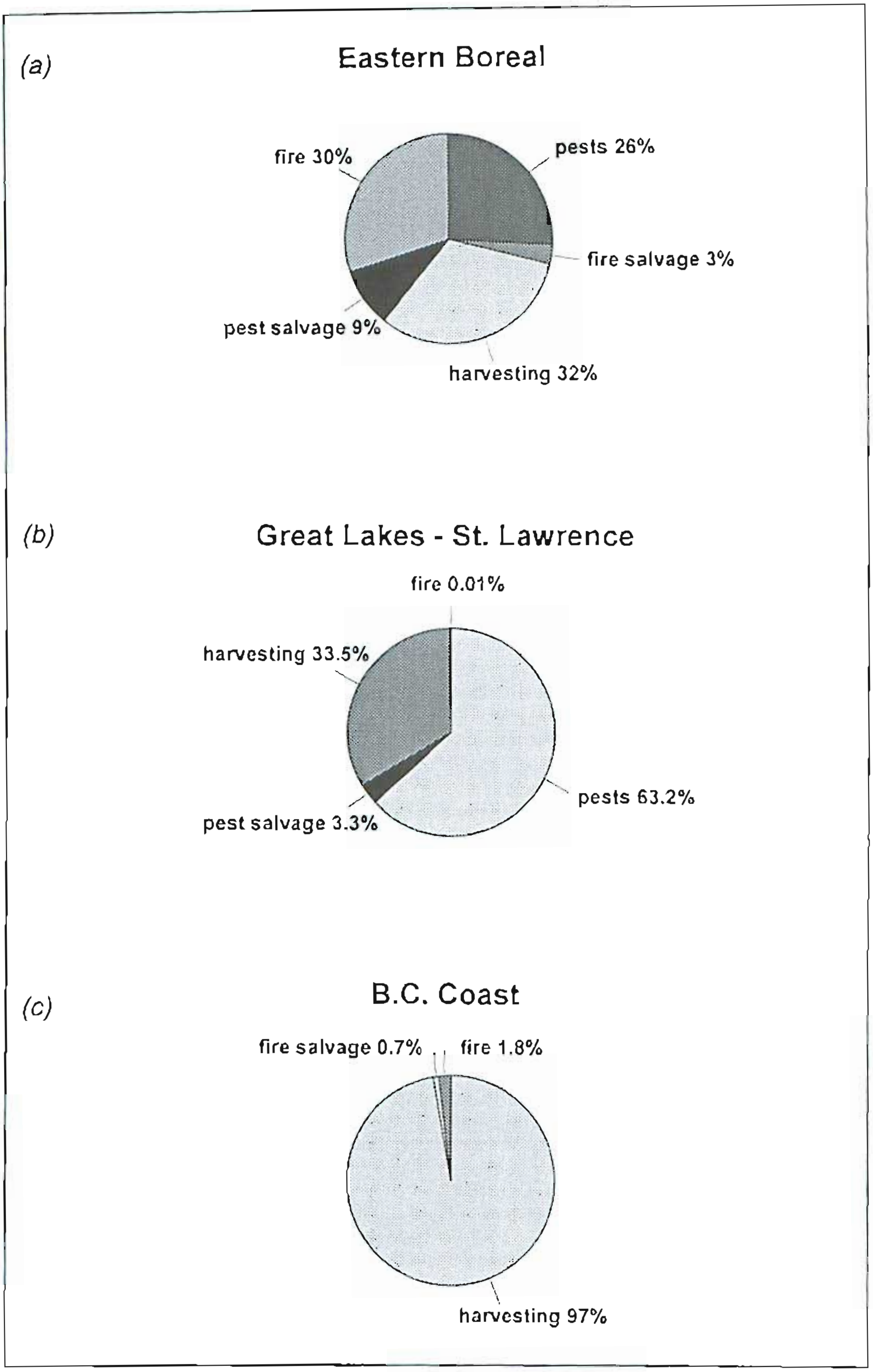

Figure 4. Proportion of forest mortality and disturbance caused by fire, harvesting, and pests across Canada: (a) Eastern Boreal; (b) Great Lakes–St. Lawrence; (c) B.C. Coast. Source: Forestry Canada (1992).

Table 4. Area harvested, harvesting method, and ownership (1991) of forests in Canada.

Harvesting method/Ownership	Area (ha)
Harvesting method	
Clearcut	738 354
Partial cut	118 750
Unspecified	2 258
Total	859 362
Ownership	
Provincial	728 835
Private	128 269
Federal	2 258
Total	859 362

Source: After estimates in Canadian Pulp and Paper Association (1992); Forestry Canada (1992).

disturb the surface soil layers of a site significantly if care is not taken. Over the past few years in Ontario, on-site chipping operations have been introduced; these operations typically involve a high-efficiency mechanical chipper, working in conjunction with a few skidders and a set of chip-trucks. This configuration is used to process harvested trees at the roadside and then deliver mainly softwood chips directly to pulp mills. The technique also introduces some specific environmental concerns about the short- and long-term impacts on the site condition. For example, the impact of full tree removal on long-term site nutrition is a concern. Often, on-site tree chipping operations require lower road quality standards (e.g., lower load-bearing strengths) than do operations where sawlogs or pulplogs are hauled from the site to the mill. One implication of lower-standard roads is that they may deteriorate rapidly after the fiber has been extracted, thus restricting access to the sites over the longer term for regeneration and tending activities.

The majority of forest planning is done at the "operational level," typically a 1:15 000 to 1:20 000 map scale. All provinces in Canada have some form of forest inventory at about this general level of resolution, but historically these inventories have been oriented towards tree volumes and species compositions, and there is not much additional "ecological" information on other vegetation, site conditions, or soils.
The perspective that should be held is that we are not harvesting 1 million hectares annually, but rather that we are harvesting 1 million 1-ha blocks (of which, admittedly, many are contiguous) annually. The "minimum manageable area" for forest practices has traditionally been 40 acres (about 16 ha), largely because of the widespread use of air photos by planners and the fact that the traditional scale of 1:15 840 shows 40 acres as a 1 in. x 1 in. square on a photo of this scale. Today, the minimum manageable area is generally considered to be about 8 ha, so there has been some shrinkage (Figure 5).

A key question is, "what is 'time zero' for biodiversity measurement?" Historical records, where they can be found, show us that the current forest covers are much modified from those of 100 years ago, particularly throughout the inhabited southern fringes of temperate and boreal Canada. In Whitney's (1987) study that was conducted in the Upper Peninsula of northern Michigan, a review of old mill utilization and timber survey records was pieced together that demonstrated a remarkable shift in mill feed over a period of 100 years (Figure 6); the records suggest that significant shifts occurred in the species mixes of standing timber for the area during this time period. Similar conditions undoubtedly occurred in parts of Canada, but there is little documentation available with which to reconstruct historical stand conditions. Given the lack of historical information, what will represent the "time zero" condition for biodiversity conservation efforts?

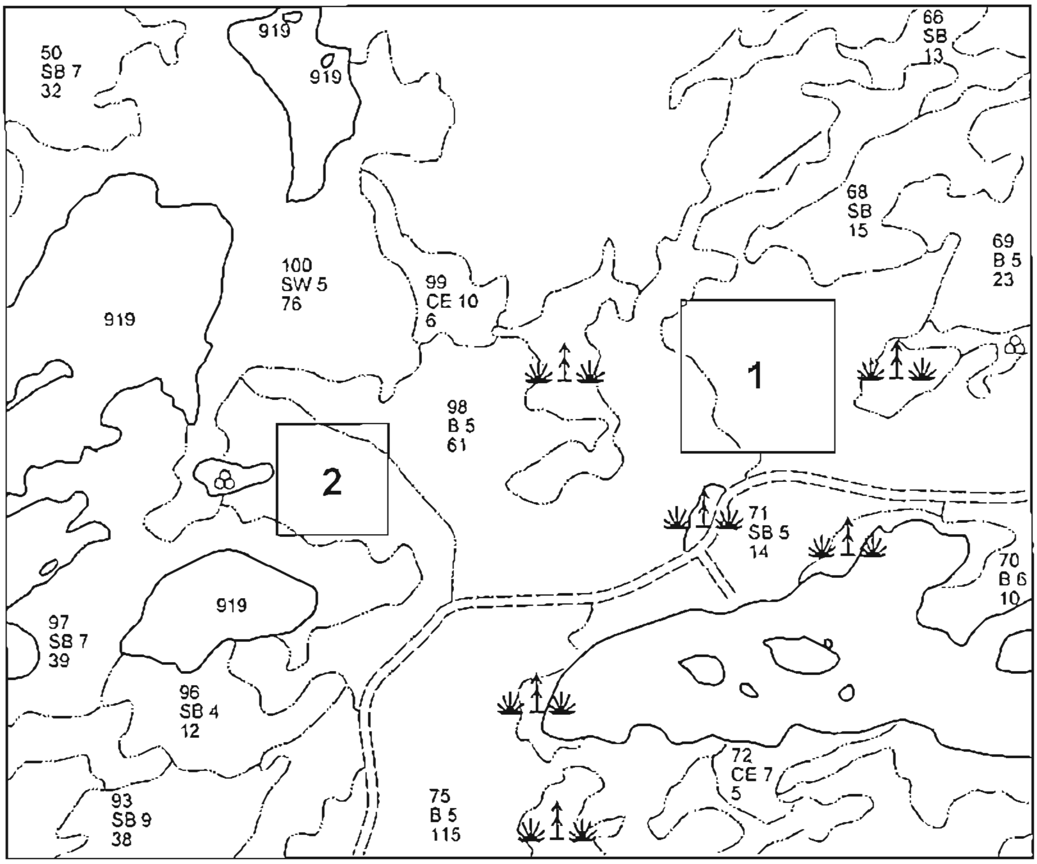

Figure 5. A section of a 1:15 840-scale Forest Resource Inventory map for a location in northwestern Ontario, showing the "minimum manageable area" for forestry practices in the past (box 1, 16 ha) and currently (box 2, 8 ha).

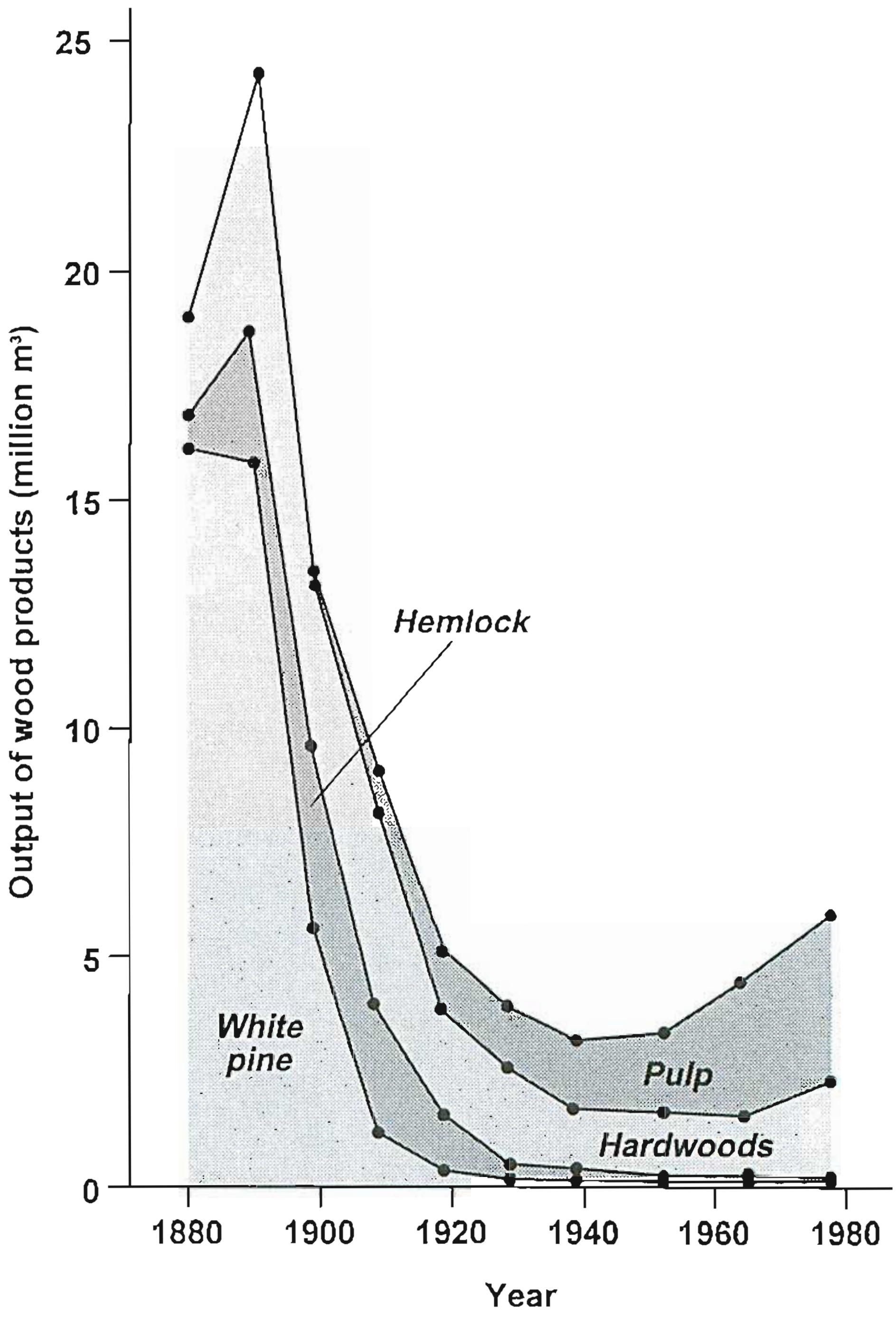

Figure 6. Shifts in mill feeds over a period of 100 years based upon surveys of mill utilization and timber survey records in the Upper Peninsula, Michigan.
Source: Whitney (1987).

Future forestry practices: some formidable challenges for forest biodiversity conservation

It is important to look closely at some of the current challenges that exist for the future in forest management in Canada. We suggest the following seven points as potential sources of frustration over the medium to long term for those who wish to see new and aggressive approaches to biodiversity conservation instituted:

1. **International and offshore market pressures will dictate the demands for Canada's forest products.** The current prediction is a 2% per year growth worldwide for forest products (Canadian Pulp and Paper Association 1992). Given this, there will be continuing pressure upon the forest industry from the marketplace for full utilization of wood materials. The annual allowable cut (AAC) is based on biological, economic, and social considerations and is set by each province. Softwood AAC has grown considerably, and hardwood AAC is now growing, especially in some parts of the country (Forestry Canada 1992). What the current overall AAC (Figure 7) does not show, of course, is the critical regional picture; in some areas, there are real shortages, the quality of the resource is diminishing, species mixes are shifting, and the age class distributions have significant gaps.

2. **Forest mill requirements will dictate the species mixes and the harvesting pressures "of the day."** Physical limitations at the mill level, as well as those sets of government regulations that are in place to enforce levels of raw material usage, effluent and pollution level outputs, etc., will continue to directly affect the woodlands operations of companies. Technological changes at the mill level, such as mill conversions or the construction, over time, of new facilities, will provide some flexibility, but these changes do not occur overnight, and they in turn are related to the financial stability of the industry at any point in time. Consequently, forest mill requirements have been in the past, and will continue to be in the future, a key determinant of where management practices must be focused in Canadian forests.

3. **Forest practices in the bush will always be dictated by the equipment that is available and the regulations affecting its use.** In eastern Canada, it is predicted that full tree harvesting will decrease from 74 to 55% by the year 2001 (Gringas and Ryans 1992). Even so, full tree harvesting will continue to be the

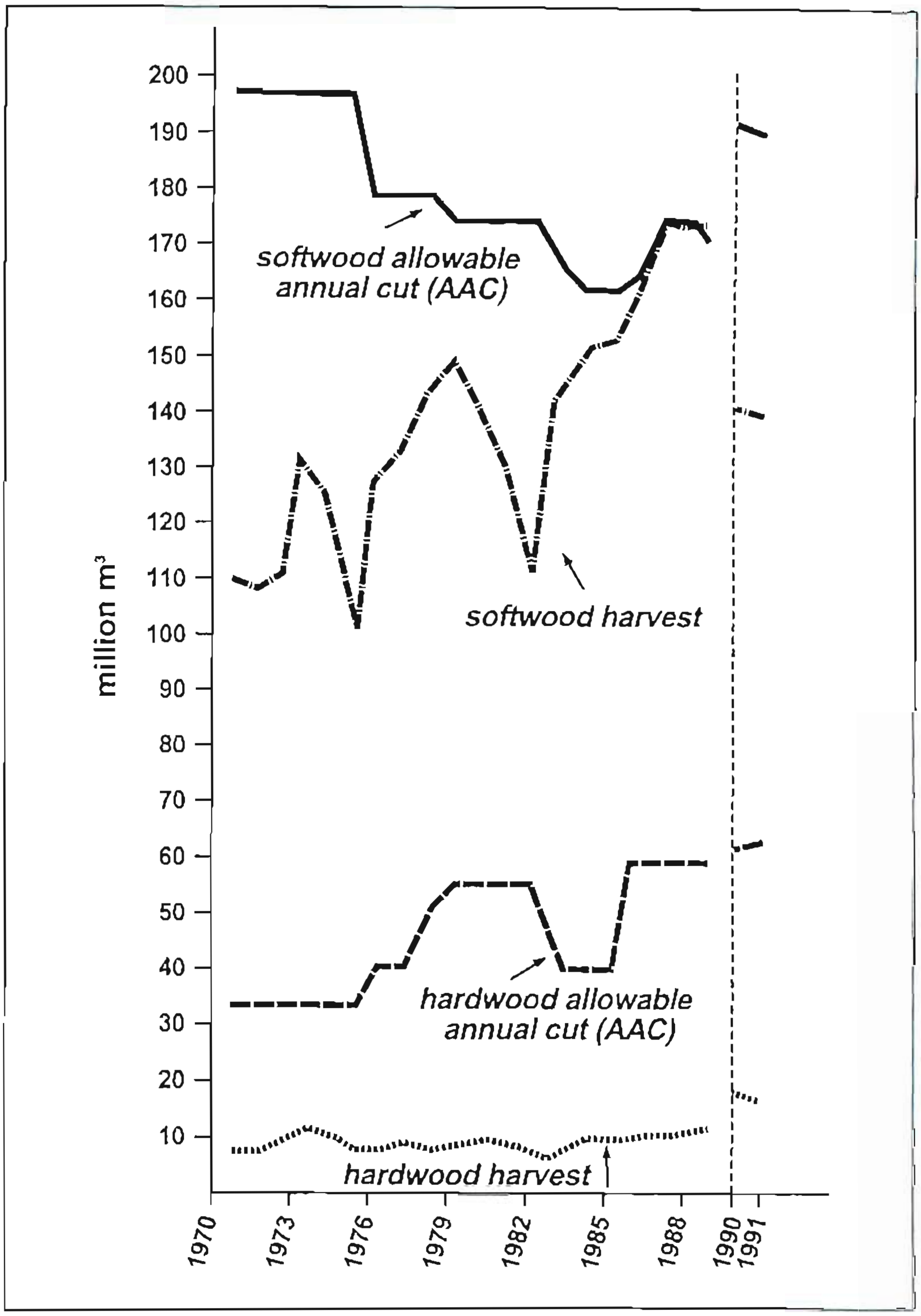

Figure 7. Shifts in utilization and softwood and hardwood annual allowable cuts (AAC) for Canada.
Source: Forestry Canada (1992).

single most widely used harvesting method as we go into the next century. The shift to tree length harvesting is a positive step ecologically; however, in some parts of the country, like those where on-site chipping is becoming a popular practice, the shift may be delayed or reduced.

4. **Nontimber, multiple-use components of forestry will become more effective drivers of planning (and therefore change) as more is learned about their value compared with wood costs.** Trends in the relative prices of logs in British Columbia since 1930 show increasingly unpredictable fluctuations (Burton et al. 1992), which have become more erratic in recent years. New "weed species" such as aspen have taken off in terms of their commercial value in the last few years in Alberta and Ontario. Such fluctuations and uncertainties in timber values make dealing with the nontimber values somewhat more problematic.

5. **Pressures from governments, labor, competitors, and the general public will force forest industries to continue to assume direct control and responsibility for forest operations.** There will be increasingly restrictive government regulations that direct the forest industry to bear more of the responsibility for all phases of forest management planning, forest land rehabilitation, and forest land research and development; at the same time, provincial governments will likely continue to move away from their planning roles and towards strictly auditing roles.

6. **Forest practices and forest management planning will continue to represent two distinct "camps"; silviculture and other activities will continue to lag well behind projected needs and desirable levels.** "Our problem is that we know how to manage better than we do" will be perpetuated in a modified version: "we will always know how to manage better than we will be able to."

7. **Ecological/environmental pressures are a wildcard, because public opinion, especially abroad, can cause a chain reaction in the six points described above, simply by altering the demands for forest products.**

In summary, changes in forestry practices in Canada are heavily influenced by economic realities, particularly the supply/demand variables. In many parts of Canada, silvicultural/ecological features tend to play a comparatively minor role.

Discussion

In developing biodiversity indicators, there is a need to be careful because there is a "moving target" involved: any set of indicators based upon current (or past) concerns/problems will need to be very resilient if it is to address conditions that exist in the future. This makes the challenge of developing indicators that are useful over time even more formidable.

It is unlikely that a common set of indicators will work equally well throughout Canada. The different forest conditions across the country exist within a wide range of "ecological/pathological rotations" or ecological cycles (e.g., fire cycles, budworm cycles) that lead to the perpetuation of forest mosaics; in the east, the natural ranges may be 50–200 years, whereas in the rain forests of the west coast, the renewal for even-aged natural stands is in the order of 700–1000 years (Kimmins 1992). The latter also do not respond to the same ecological "rule-sets" that exist in eastern Canadian forests.

Some level of resilience is already "built in" to Canadian forests, as most are associated with catastrophic natural events that led to renewal and regeneration. However, with the addition of a wide range of forestry practices, the question becomes: "what is the limit of tolerance that exists when the natural system is stretched?"

Currently, levels of impacts associated with most forestry practices are not suitably quantified; that is, they are not effectively and precisely ranked into suitable classes—not disturbed, somewhat disturbed, disturbed, very disturbed, and hammered—that can in turn be defined in terms of acceptable probabilities. The next step is to determine the scientifically acceptable focus for efforts to conserve or maintain a given index or indicator of biodiversity. For any application, there is a need to focus on the appropriate range of conditions.

Dealing with a comprehensive theme such as biodiversity requires an across-the-board examination and knowledge of the sciences involved. To define adequately the mean values, ranges, thresholds, and limits for many of the variables that are required, there is a need for a full understanding of the elements and processes involved. The exercise of formally defining forest biodiversity indicators when applied to Canadian forests will undoubtedly quickly uncover some of the many "scientifically weak links." The weaknesses include, for example, the need for better scientific understandings of:

- successional pathways;
- wildlife behavior and response to disturbance regimes;
- long-term versus short-term ecological effects of disturbance regimes;
- physiological and symbiotic relationships of trees;
- all below-ground interactions, functions, and processes;
- carbon cycle components over time, especially in relation to disturbance regimes;
- global effects (forest health, climate modifications, etc.); and
- valuations of nontimber features.

However, we have faced the dilemma of information shortages in forest science before many times, and this is not a reason to defer or suspend attempts to derive, develop, test, and employ biodiversity indicators. It does mean that it may take time and effort, and many iterative revisions, to improve and refine the array of indicators that are required. For example, the development of the national forest fire danger rating (Forestry Canada 1992) began with limited data and many assumptions and has been successively improved, modified, and expanded over many years as new knowledge and information became available.

Acknowledgments

We would like to thank Fred Haavisto and John Jeglum for their helpful comments and ideas during the early development of this paper.

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A Biological Conservation Perspective on Forests

Daniel A. Welsh

It was with considerable trepidation that I agreed to undertake this talk because it seemed to me that I would be "carrying coals to Newcastle." The problem I imagined was that I would be talking about biological conservation to a group of people who were already, in various ways, experts.

Forest land management practices have inescapable consequences for the conservation of biological diversity. In recent newsletters, Greenpeace International (Greenpeace Forestry Campaign, June 1993) reported that an area of forest the size of the Netherlands is cut down in Canada every 3 years and that Canadian clearcuts range up to 2500 km^2. It claims that "by the Canadian forest industry's own account, it is currently cutting well above a sustainable level" and that "forest management policies in Canada have been for a long time based on the liquidation of the old growth forest resources." By its calculations, "almost 1 million hectares of forest is lost to clearcutting every year in Canada."

At the same time, the Food and Agriculture Organization (FAO) reported (in Schröder 1994) that the "net annual balance between increment and fellings leads to the following distribution for exploitable forests (in % net surplus): North America + 26." In other words, the FAO believes that the forests are growing faster than they are being harvested and that there is therefore a surplus to be harvested. These two polar extremes on Canadian forest management provide guidance on the topic of indicators for forest biodiversity, and we will come back to them.

There seems to be agreement to accept a definition of biological diversity similar to that of the United Nations Conference on Environment and Development (UNCED 1992):

> Biodiversity is the variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.

It is extremely important to recognize that throughout much of the world we now hear the challenge to conserve biodiversity and practise sustainable development. At UNCED, we had a clear message that the world's leaders were prepared to adopt the challenge. Canada was a leader in promoting the adoption of the declaration, and as a nation and on provincial and regional scales we are developing policies and strategies to conserve biodiversity.

Frequently, as well, we hear detractors saying that they do not understand or that biodiversity is too complex and imprecise to deal with, but they have missed the point. As a nation, we have now ethically embraced the principles of sustainability. In the words of the World Commission on Environment and Development, sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The spirit of these ideals is not difficult to understand; what is difficult is determining where to best place our efforts, on what aspects of sustainability and on what measures of biodiversity conservation.

The challenge for the scientist and forest manager is to provide leadership in working towards the ideals. This meeting is on "indicators of biodiversity," which is part of the requirement; however, what is really needed is a framework for measurement and description so that we have a sound context within which to measure our progress or lack thereof.

Current state of forest resources

Recently, we have seen an increasing proliferation of reports assessing the state of the environment or of a specific resource. To me, this trend is a signal that there is increasing recognition that to increase our conservation effectiveness in the future we need to know in precise detail what the "current state" is. To give us a basis for our discussions over the next few days, I have selected a few examples of boreal forest studies.

Fire and cutting

Near Manitouwadge, on an area of over 10 000 km^2, we found that from 1760 to 1880 about 80% of the land was disturbed by fire and that most of that disturbance occurred during three major fire seasons. When we compare the spatial and temporal patterns of current cutting, we immediately recognize that our cut patches are relatively small compared with fire damage and that they occur more regularly and with greater frequency. The basic age structure of the new landscape is different. The boreal forest is boreal in large part because of the characteristic dynamics of disturbance patterns. Frequently it is said that clear-cutting simulates natural disturbance, but I would argue that there is little evidence to support that contention. In Ontario, according to Ward and Tithecott (1993), the average turnover due to fire is now 578 years, in contrast to the turnover of 65 years before we began to suppress fires. If you add the amount cut each year to the amount that burns, on average, the total is less than the average amount burned before fire suppression; therefore, the forest must be getting older. So why do we say that cutting emulates fire?

Forest birds

The approximately 150 species of birds that live in the boreal forest of eastern Canada show a remarkable degree of adaptation and specialization. Without going into extensive detail, it is informative to look at their species occurrence patterns in relation to two major forest attributes—age and stand type.

When we examine species distribution in relation to age (Welsh 1987), it is clear that most species have a preferred age of stand with which they associate. We find that species like alder flycatcher, mourning warbler, and chestnut-sided warbler occur only in young stands, whereas golden-crowned kinglet and Cape May warbler are associated with old forest.

Recently, in northwestern Ontario, a vegetation classification system (Sims et al. 1989) was developed that recognizes 38 distinct vegetation ecosystem types in mature forest. If we examine bird distribution in relation to the vegetation types, we find (D.A. Welsh and L. Venier, unpubl. data) that the bird distributions reflect the V-type distribution. For example, we observe that Connecticut warblers are concentrated in the wet black spruce types (V-types 35–38), whereas scarlet tanagers associate most strongly with mixed aspen and some rich mixed-woods (V-types 6, 8, 12, 13, 26).

What to measure?

It has been remarked that if we were to know any one thing in its entirety, then we would know everything in the universe. In the case of biodiversity, we currently have a great deal of information that we could deal with; the challenge will be to select the right bits and organize them in a structure that is useful, one that will answer our questions. The attributes we measure must meet basic criteria for scientific measurement, reflect human values of what is important, and be selected to give maximum warning of developing problems.

The question of what to measure seems to cause extensive consternation, and all too often the "facts" that are presented about conservation are irrelevant because there is no context within which to evaluate them. We are told that the species living in a 200-year-old forest have been "lost" through harvesting because they do not live in the resulting cutover, but we are never told that the species associated with young forest have been "saved" and have a new home. What we really want to know is, do we have the right balance of young and old forests to sustain species and maintain function and process? In the case of the FAO statistics presented above, what is missing is an understanding that the forest needs to be managed for a large number of features to be sustainable. The FAO neglected age structure and biota, so its calculations became irrelevant; Greenpeace missed the point because it did not tell us if the forest age balance is being kept. Is it getting older or younger—what does "lost" mean?

Last year in Ontario, a large study of regeneration following forest cutting (Hearnden et al. 1992) found that overall forest composition is changing. For example, the original forest was 18% spruce and 10% hardwood, whereas the new human-made forest is 4% spruce and 19% hardwood. In another recent study (Whynot and Penner 1990), a comparison of cut and naturally regenerating claybelt forest showed that in the conifer–herbmoss rich type black spruce, volume is dramatically less in cut stands for at least 40 years following harvest. These two studies are helpful because they tell us how things have changed in a context that makes the information useful for evaluating an impact on the environment.

Framework for biodiversity indicators

Sustainable development and biodiversity conservation are about "having our cake and eating it too." We want to be able to use our natural resources so wisely that we never use them up. To do that, we really need a good accounting system to see if we are balancing the books. The following suggestions can be viewed as elements of such a system.

Current attributes

The first task is to characterize the attributes of the system—what is the present forest like? What are its elements (vegetation types), and how much of each is there? What other species are associated with each type? Which of these are good indicators of system function and the presence of other species? Clearly, we want to ensure that the ecosystems we manage remain productive and are not degraded by our actions, so we will choose abiotic and biotic measures that describe nutrient status and other aspects of function and process. We will use species in their own right, but also because of what they tell us about the system.

Our system will give us a static, instantaneous look at where we are now. Ideally, if that information were georeferenced to a spatial data base that described all the primary attributes like topography, bedrock, soils, and climate, we would be well situated.

Monitoring

Once the overall description of composition, function, and process is in place, we need to measure appropriate system attributes regularly in a context that allows us to quantify natural change and changes resulting from our actions. This requires both adequate control areas and an adaptive management approach (Holling 1973) in which we treat all human actions as an experiment and carefully measure their effects.

Expectations—history and modeling

If we know how a system has changed over time—for example, a species may have increased or decreased or a nutrient pool may be larger or smaller—we need to have expectations to evaluate the change. It is normal or abnormal? The best data will come from two approaches: the first is to have comparable undisturbed examples to compare with, and the other will be from models. One type of model needed is one that predicts what the future will be like based on an understanding of the past.

In some cases, we have adequate historical records for recent times, but not very many, and over too short a time frame. What we need to do is reconstruct using a range of tools like old descriptions, pollen history, and other records. These reconstructions allow us to develop or model trajectories of what types of changes we can expect. The combined expectations from observations of natural undisturbed areas and models will allow evaluation of changes and tell us how we have done in the business of complete forest management.

To summarize, our biological conservation framework needs to contain three elements:

- an accurate, ideally spatial, description of the present attributes of the system, including both structure and function;
- a monitoring system to measure how the system changes over time; and
- a good set of expectations for what should happen over time, based on models and the study of undisturbed areas.

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Saving Species versus Saving Ecosystems: Is There a Conflict?

Michael E. Soulé

Preamble

To simplify things, let us say that there are two kinds of intellectual activities: normative and non-normative. In the former, we seek the good and the beautiful. In the latter, the non-normative, there can be many objectives; however, if we are concerned with science, the objective is the truth—the way things really are. Conservation biology (CB), like forestry, range management, fisheries biology, and wildlife management, is a mission-oriented (or normative) discipline; it searches for the truth but *in service of the good*. In other words, it is based on certain values. Conservation biologists seek to provide the knowledge and technology that people in the conservation movement need to do their work.

However, the values of CB can differ from those of the resource fields. For CB, biological diversity itself is good, evolution is good. CB is concerned with preservation of biological diversity and wilderness in the tradition of John Muir, and preservation has a higher moral standing than does commodity production and recreation. For the natural resource fields, the good can be defined as that which serves the higher needs of human society. In contrast, the conservation biologist believes that the world is larger and more important than humanity alone. In actual practice, however, the two fields may select quite similar approaches, because the fulfillment of human needs is often a necessary means, a pragmatic expedient, for the protection of biotic diversity.

It is not always possible, however, to harmonize human needs and biodiversity protection. The natural resource fields are concerned with human welfare or happiness, as represented by productivity, recreation, and meeting other human needs, both short-term and long-term, in the tradition of Gifford Pinchot, Ducks Unlimited, The Wildlife Society, and the economic viability of human communities whose livelihood may depend on grazing, logging, mining, tourism, and other forms of extraction.

Although conservationists and resource managers have many values in common, it would be foolish for members of either group to assume that the other's values were their values. (Moral dilemmas occur when a person is a manager in public but a conservationist in private.) There is one goal, though, that they must share—the achievement of workable compromises about land use.

One of the currently fashionable buzzwords for this rapprochement is "ecosystem management" (EM). An often-stated goal of EM is to facilitate the marriage of economy and ecology. The EM idea is fuzzy, and the current fashion of species bashing and opposition to species-based approaches among some of the proponents of EM is wrong-headed and potentially a threat to biodiversity and wilderness.

Criticisms of the species approach

The limitations of the so-called "species approach" to the protection of biological diversity have recently been pointed out with considerable success by many authors. Some of these critics belong to the so-called "wise use" movement, which is funded by off-road vehicle (ORV) manufacturers and by corporations that benefit from the extraction of natural resources from public lands. However, there are also critics of the species approach among committed conservationists. Let us examine some of the latter group's major criticisms of the species approach to conservation; they include the following:

1. It cannot, by itself, justify a comprehensive network of protected areas that ensure the survival of examples of all the world's biotic *communities* (which in theory are infinite in number).

2. It may not address ecosystem *services* and maintain ecosystem *functions*.

3. It may ignore issues of reserve *design*: shape, size, scale, and connectivity.

4. It may not incorporate all elements of diversity, such as biotic *gradients* and habitat *mosaics*.

5. It may ignore the dynamics of *disturbance* regimes.

6. It may not consider long-term *global change.*

7. It may not be *cost-effective.*[1]

8. In the United States, endangered species legislation such as the Endangered Species Act (ESA) is *failing to stem the rising tide of candidate species.* In addition, critics say, the management efforts of government agencies have focused on too narrow a range of species, primarily large vertebrate, commercial, and sport species, often to the exclusion of plants, invertebrates, and sensitive species, or species that may act as indicators of environmental "health." A related criticism is that many species are listed when it is too late or too expensive to achieve recovery.

Besides these general criticisms, the ESA is subject to another set of specific or technical criticisms. One of these is that it may "overprotect" some entities such as subspecies and underprotect other entities such as distinctive or relict species and lineages.

The argument that the ESA is too egalitarian is compelling; for listing purposes, the act ranks as equivalent, for example, a threatened subspecies of an otherwise common species along with a rare, endemic, or relictual species that may be the only living representative of its genus or family. This egalitarianism at the listing stage, however, surely does not continue during the recovery phase. As Stuart Pimm (1991) noted in a book review, spending over $20 million to save the Mississippi sandhill crane (a subspecies) and more on bald eagles than on any other single species, while very much less to save the very large number of critically endangered species of plants in tropical forests of U.S. states and territories (Hawaii, Guam, and other Pacific territories, Puerto Rico and other Caribbean areas), is "inexcusably provincial."

1 See Grumbine (1990) for references. See also Salwasser (1991) and Scott et al. (1991).

Many critics of the species approach[2] argue that precious resources are wasted on the crisis management of endangered species and subspecies, some of which have more popular appeal than scientific or conservation merit, and that monies would be better spent on prevention of endangerment in the first place—that is, on efforts to sequester so-called whole systems.[3]

I must say, however, that it is a sign of political naïveté to expect a single law, regardless of how well formulated, to solve all of our problems. Sometimes a good law can raise awareness and produce a change in values, but more often a change in values must happen before laws are enacted. Enforcement is even more problematic. Not only is eternal vigilance necessary to ensure that a law is enforced, but most governments in the world do not have the resources to enforce laws effectively, even if they wished to. In any case, the ESA was a legal fluke—no one expected that its political and social ramifications would be as great as they have become.

Behind much of the current hand wringing over the species approach (and the excitement about a broader ecosystem approach) is the idea of prevention or anticipation of biodiversity problems before they become acute. Most people want to avoid chaos and logjams—they want to prevent species from becoming endangered in the first place. Politicians, in particular, want to avoid judicial fiats that lead to complete cessation of exploitive, commercial activities, such as happened with old-growth logging in some parts of the Pacific Northwest over the spotted owl, and which are likely to happen again over salmon in the same region.

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2 Although I have used the term "species approach" as if it were understood, it is clear that it means different things to different disciplines. Most academic biologists and conservation biologists equate the species approach in conservation with an emphasis on endangered species, particularly rare vertebrate species such as spotted owls and wolves. Wildlife biologists, on the other hand, generally equate the term species approach with the management of harvestable resources, such as deer, turkeys, ducks, and salmonids.

Wildlife biologists and managers, like conservation biologists, are now beginning to reexamine the species approach because they recognize that production and diversity of resources such as many anadromous fish stocks cannot be achieved unless one manages the entire ecological–political system, including the oceanic fisheries and marine mammal populations and the lands subject to timber harvesting. In other words, even the management of a single species for consumption and recreation can become geographically and politically extensive, involving ecosystems and institutions far away from the local administrative unit. In such cases, the line between species management and system management is obscured.

3 For Ted LaRoe (1993), ecosystem management is multispecies management based on a gap analysis that helps to avert listing. "The time to protect a species is when it is still common."

The many uses of the term "ecosystem management"

Although it has been fashionable to criticize the species approach in recent years, there has been less attention paid to defining, clarifying, and critiquing the "ecosystem approach" and to the popular idea of "ecosystem management." To begin with, there is considerable confusion surrounding the meanings and definitions of these phrases. Actually, there are at least five such ecosystem approaches or goals of EM; some managers and scientists emphasize only one, some emphasize several. These objectives include:

- protection of the entire range of *ecosystem types* (usually plant communities), regardless of their contributions to local or regional processes and services; this requires the description, classification, and mapping of all of the plant/animal associations in the region of interest;
- protection of (sustain, conserve) ecosystem *services* for human welfare;
- protection of (sustain, conserve) ecosystem *processes*, including the continuation of natural *disturbance regimes*;
- protection of ecosystem *health* or *integrity*; recently, the idea of ecosystem *resilience* has been promoted, although logically it is an aspect of integrity; and
- protection of the *balance* between human economic needs and biodiversity conservation; encourage and maintain harmonious interactions between humans and nature, emphasizing the development of means to ensure the economic and ecological sustainability of exploitive land uses. This is the definition favored by UNESCO's (United Nations Educational, Scientific and Cultural Organization) Man and Biosphere Program—the biosphere reserve approach—and by such organizations as Conservation International and the U.S. Forest Service.

Although all these objectives have their virtues, it is often unclear to which of them people are referring in a given context. More important, there are scientific/conceptual and practical problems with all of these concepts. In addition, serious conservation and public policy issues arise when we rely exclusively on any one or even on all of them. What are the problems?

1. A universally acceptable *classification scheme* for biodiversity does not exist; a related problem is that there are nearly an infinite number of biotic communities (depending on how finely we subdivide associations or "ecosystems").[4]

[4] For examples of such fine subdivision, see articles by Barnes (1993) and Rowe (1992).

Descriptive methodologies, including gap analysis and other ways of identifying and locating candidate entities, cannot protect biodiversity or ensure long-term viability. This is not a criticism of gap analysis; this and similar approaches were not designed to be prescriptive. Not only do these approaches beg the question of what we mean by "ecosystem viability"—a nebulous concept given that the membership of any given biotic association is constantly changing—but the design (how large, how connected) and management of protection systems are logically the next steps. Identification of things to protect is one process; protection is another.

2. The provision of *services* for society, such as plentiful, clean water from wetlands and rivers, waste treatment from wetlands, recreational opportunities from forests, fish breeding and nursery facilities from estuaries, climatic buffering by forests, and watershed protection by scrublands and grasslands, is essential for human well-being. But even if we accept such an anthropocentric definition of EM, it leaves unanswered the critical question: how much of each ecosystem is necessary, how big an area do we need? It ignores the whole issue of population viability and treats species as though they were interchangeable, anonymous cogs. A pure "service approach," therefore, could be insensitive to the richness and survival of native species.

3. The approach favored by many ecosystem ecologists is to ensure the continuation of ecosystem *processes* and natural *disturbance regimes* (e.g., see Fiedler et al. 1993). Examples of processes include fire, hydrological regimes, and the dynamics of natural disturbances such as floods and windstorms. The intention is excellent; managers must attend to the conservation and sustainability of ecosystems instead of sharply focusing on the productivity of individuals or competing resources such as timber—which has been the traditional mode of operation for most government agencies. In practice, however, a process approach can be perverted and oversimplified, resulting in significant losses.

The focus is usually on disturbance. Disturbance occurs on all scales—from the local patch to the entire planet. We also know that each scale has its own characteristic kinds, intensities, and frequencies of disturbance. It is also understood that certain levels of disturbance are necessary for maintaining the diversity of patches and habitats that support the full range of native species. Levels of disturbance that are either too high or too low can reduce habitat and species diversity. Fiedler et al. (1993) stated that single-species management of fire-prone ecosystems is simply inappropriate, given the vast number of rare and/or endangered species, and would likely jeopardize landscape heterogeneity. "By managing fire as a process, we are assuring the perpetuation of naturally diverse landscapes on several spatial scales." With regard to water, "the goal is recovering entire assemblages of threatened organisms to affect recovery of a declining ecosystem by managing physical processes such as water flow."

Good intentions alone, however, are no insurance against bad science. For instance, a persistent myth in forestry is that increasing the diversity of habitats, per se, is beneficial to wildlife; for example, foresters often say that logging benefits wildlife, but logging, although it is beneficial for certain species such as deer, is harmful to many others, including those that require nearly undisturbed, interior forest, those that require complex vertical and horizontal structure, and aquatic organisms such as salmon that require unsilted streams.

The proponents of large-scale process management must also address the issues of design and viability, particularly the viability of rare or highly interactive species as outlined above. Nature is not just process; it is pieces too.

4. Concepts like *health, integrity*, and *resilience* are difficult to define and operationalize and can lead to a false sense of holistic, new age warmth; we must ask the popularizers of these concepts to quantify and to set thresholds of acceptability. This is being done for some systems, especially aquatic ones, but what we discover is that resilience and integrity are often defined in terms of maintaining the populations of certain species within acceptable limits. Thus, we come back to species (Karr 1991; Cairns et al. 1993).

5. EM is often equated with the concepts of *sustainability* and *harmony*. One of the many problems with these terms is the tendency to ignore the growth of human populations; it is often absurd to claim that it is possible to support expanding populations on a finite base of wildlands while maintaining the diversity of native organisms throughout their original geographic ranges. The obvious conflicts are ignored, sometimes for political purposes. A related problem with

the idea of harmony is the premise that humans and nature have common interests and operate on similar time scales. However, irreconcilable conflicts occur when one party (local humans) has short-term economic profits or survival in mind and the other (conservationists) has long-term sustainability in mind. It is impossible to maximize human well-being in the short run (i.e., a political time scale) and the well-being of biological diversity in the long term (i.e., an ecological time scale).

Hoping to overcome this dilemma and ignoring the inherent contradictions, the U.S. Forest Service, decades ago, adopted the multiple-use philosophy. It is now clear that this approach has often caused the overexploitation and simplification of biotic communities. It is absurd to think that adding an additional use for forests (the protection of biodiversity) while not eliminating or reducing the intensity of extractive uses is a viable policy.

This idea of the sustainable exploitation of wildlife (including plants) resources is the essence of the biosphere reserve concept. Attempts to implement the idea of harmonious codevelopment and coexistence of people and wildlife in developing countries, although emphasizing the benefits of natural areas to humans, have rarely been successful, however.

One problem with such a philosophy is actuarial: a given nature reserve has a finite lifetime, shorter in Africa, longer in North America. The half-life of a reserve depends on such factors as the frequency of famines and wars. This is why some conservationists suggest a policy of hedging our bets, not emphasizing reserves to the exclusion of ex situ, backup approaches. Given the momentum of the population explosion and the apparently chaotic dynamics of famines and warfare, how much of our biodiversity capital should we spend on a biosphere reserve system, when many of its component reserves are likely to perish in any given time interval? Consider the recent and current chaos and its devastating impacts on national parks and similar reserves in Liberia, Mozambique, Angola, Sudan, Somalia, Ethiopia, Uganda, Zaire, and Nigeria, to name only some of the countries in Africa where important conservation investments, based on the premise of harmony, have been or are now being ravaged. Conservationists must be realists, not idealists.

My objective in pointing out some of the problems with these uses of the EM concept is to emphasize the need for a synthetic approach that incorporates the five kinds of EM described above *along with species-based approaches.* Such a broadly ecological philosophy has, unfortunately, also been referred to as "ecosystem management."[5]

Hawaii: a case study

To demonstrate the wisdom of an ecological, synthetic, truly multiscale, multilevel approach to the maintenance of biodiversity in wildlands, consider the task of protecting the flora and fauna of densely populated islands like the Hawaiian chain, where the vast majority of native species are endemic. The history of colonization and its impacts is relevant.

The fate of the Hawaiian avifauna is typical of oceanic islands. Over half of the native bird species on the chain were destroyed by the Polynesians who converted most of the lowlands to agriculture; over half of the bird species remaining at the beginning of European–Asian domination are now extinct or endangered (for references, see Wilson 1992). The islands, most of which are covered and fragmented by farms, plantations, cities, factories, and networks of roads, have also been subject to the introduction of thousands of non-native plants and animals, more than 100 of which have already become naturalized and are invading the remnant native ecosystems. These include introduced mammals such as rats, mongooses, pigs, goats, and sheep; invertebrates such as earthworms and predatory snails, some of which have decimated the native land snails; many invasive plants, including lantana, banana poka, and nasturtiums; and, finally, disease vectors and pathogens to which the native fauna have little inherent resistance.

The surviving native communities and species on the islands, most of which are now restricted to the higher elevations, require a spectrum of therapies, most of which are *species oriented*—they require knowledge of the natural history and autecology of species, both endangered and exotic. Among the necessary conservation techniques are germplasm collecting and captive breeding of some of the most endangered species, tighter quarantine for the prevention of further introductions of exotic species, the

[5] Clark and Zaunbrecher (1987), Clark and Harvey (1988), and Grumbine (1990) employ two species-level criteria as well as the above ecosystem criteria. The species criteria are to maintain viable populations of all native species throughout their ranges; and to manage the system such that these native species should persist without reductions in viability for 1000 years or so.

extirpation of feral pigs, the control of exotic predators such as rats and mongooses, the careful introduction of some organisms for the biological control of harmful exotic species, planting of native trees, and the establishment of special preserves and corridors to facilitate recruitment and dispersal of native species. In other words, the protection and management of biodiversity require the protection and management of species.

When we consider the design of protected areas and their management, the species is usually the appropriate source of guidelines. Species-based research is the basis for understanding deleterious edge effects. Population viability analyses of vulnerable species are one of the few bases for determining the optimal sizes of protected areas and other "design" features such as shape and distance between habitat fragments, not to mention management protocols at the system level, including the optimal scale and frequency of disturbances.

At the community and ecosystem levels, one of the most important management interventions is the control of exotic weeds such as fire-conducting grasses that can quickly eliminate forests and most of the species that they harbor (Smith 1985; Vitousek 1988). Even the continuation of cattle grazing to control some weedy plants may be recommended in such situations. All this complexity is a reminder that effective conservation requires knowledge from systematics, biogeography, population biology, and community and ecosystem ecology.

The Hawaiian example underlines two points about managing the remnants of biodiversity. First, it is *contextual*; rarely, for example, will the methods required to extirpate a particular exotic species in one place work just as well somewhere else. The control of goats on the island of Hawaii, for example, was achieved by quite different methods than it was on the Channel Islands off California, in part because of differences in the terrain, in part because of less attention from animal rights activists. The cultural and economic contexts are also important. Most tropical nations lack funds for research, and the effective enforcement of laws is precluded by corruption and the conventional tolerance of nepotism and bribery. In Hawaii, on the other hand, antipoaching laws can be enforced, although not with complete effectiveness. Also, Hawaiian agencies and nonprofit organizations have funds for research, and the infrastructure is in place to conduct it.

The second point is that most management activities, whether on islands or on the mainland, are carried out mainly by the *manipulation of species* (Frankel and Soulé 1981),[6] although not all of these species are endangered. These manipulations include the control of destructive native species such as deer and cowbirds, the control of alien species such as pigs and weeds, the reestablishment of native tree species or native predators,[7] and the enhancement of an economically valuable species. In other words, in most cases ecosystem management is species management. This is not to devalue the importance of management techniques applied to whole systems, including burning,[8] the artificial control of water flows by the flooding and draining of wetlands, and controls on nutrient discharges into lakes. However, more often than not, these system-wide manipulations and perturbations are chosen because they favor desirable species or discourage undesirable ones.

Discussion and conclusions

Critics have attacked species-based approaches because our laws have not succeeded in bringing many species back from the brink, because agency biologists have devoted nearly all of their efforts to making more white-tailed deer, ducks, and trout, and because such approaches do not prevent species (and ecosystems) from becoming

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6 It should be noted, however, that those who attack the species approach are usually referring to endangered species, not those species that must be managed for the protection of biodiversity in general.

7 The roles of so-called keystone species (see Mills et al. 1992, who recommend that this term be restricted to popular exposition) provide many examples. Keystone is a popular term for those species whose disappearance initiates a cascade of linked extinctions. The dominant role of such interactive species, combined with the sensitivity of many of them to habitat fragmentation and edge effects, is the main reason for insisting that any strategy for the maintenance of biodiversity in situ be based on the minimum spatial (including genetic and demographic) requirements of such species. For example, trees of the genus *Ficus* provide essential food for many large animals in the New World Tropics during seasons of scarcity (Terborgh 1986). Large or social animals such as termites, groupers, predatory starfish, beavers, wolves, coyotes, howler monkeys, or elephants are important in the long-term maintenance of habitat diversity in their respective systems, and special attention must be devoted to the needs and viability of their populations within the protected area (Botkin 1990). The disappearance of a mutualist species, such as pollinators, can also produce ripples of extinction (Gilbert 1980). Because bats, for example, are important pollinators of many tropical plants, it will be necessary to ensure that their roosting and breeding sites are protected within the system of protected areas, and that the human activities around and in the reserves do not compromise their long-term viability. The control of harmful exotic species also requires deep behavioral and ecological insight. Clearly, the effective management of wildlands will require extensive knowledge of species and of the processes that affect their viability (Soulé 1987).

8 Hillel (1991) suggests that humans have changed huge regions of the planet by purposeful burning to create better hunting and grazing conditions. The long-term effects, though, have often been devastating when such burning has promoted soil erosion.

vulnerable to extirpation. The false conclusion is reached that we should abandon the emphasis on species and turn to some other approach—EM. Such critics fail to note that there never has been implemented a real species-based management program—one that incorporates all species and their habitats.

The attack on species-based approaches can backfire, and we see evidence that it has. Naive "experts" may claim that species-based approaches are inherently bad and must be replaced by approaches that are based not on species at all, but on some other biological qualities or ecological scale. This is dangerous. It is throwing out the baby with the bath water.

Constant repetition of the mantras of "sustainability" and "holistic ecosystem approach" will not, by itself, lead to a truly synthetic, ecological approach to management. In fact, management will always be site specific and based to a large extent on single species. The current fashion of species bashing is antiscientific and provincial, especially in view of the environmental conditions in many tropical nations and the high probability that many large animals will not persist in nature in large regions of the world during the current and coming episodes of overpopulation, humanization, and denaturation of landscapes and aquascapes, the "demographic winter."

I contend that nearly all management activities, at whatever scale, are species-based activities, not ecosystem-based activities. Certainly this is true for commercial exploitation. Fisheries biologists manage particular species; the same is true for foresters. At any one time, only one or two commercially desirable species are favored; the rest are considered "trash," at least until the desirable species, whether they be cod, lake trout, bluefin tuna, white pine, ponderosa pine, or Douglas fir, are overexploited, as they usually are.

Many noncommercial consumptive uses of wildlife and their management are species based as well. Sport fishermen prefer pike, bass, salmon, or trout, not the entire community of species. Hunters do not hunt deer and ducks at the same time.

The more we learn of ecological processes, the clearer it becomes that management must usually be addressed to species—endangered species, alien species, weedy species, disease-causing species, resource-providing species, pest species, and disturbance-causing species. At the same time, issues of scale and connectivity must be borne in mind. Therefore, neither a pure endangered species approach nor a pure ecosystem process approach (assuming the existence of such pure forms) can provide a set of universal rules for locating and designing conservation systems, for identifying indicators of the status of biodiversity, or for selecting tactics for maintaining and managing wildlands and waters. Both approaches in their pure forms are biologically indefensible, and, taken to their logical extremes, the pure pursuit of either one would be disastrous.

Nothing could be more absurd biologically and philosophically than a debate, for example, over whether the best way to define and protect the Yellowstone ecosystem is in terms of species or in terms of plant communities or landscape elements. A naive but pure species approach would call for minimum viable populations for "keystone" and numerically rare species such as moose, elk, bison, grizzly, wolverine, and wolf, but it might ignore their need for different resources and habitats and their seasonal migrations. On the other hand, a naive but pure ecosystem approach would ignore the species and base the management of Yellowstone on securing a sample of each landscape element (plant community) and by establishing upper and lower bounds for such processes as nutrient leaching and primary production. However, this approach ignores the size of landscape elements necessary to maintain vertebrate diversity, the spatial relationships of landscape elements, whether there are barriers to dispersal and migration between the elements, and the roles of species like beaver and grizzly, whose activities create sites for disturbance-dependent species. In other words, a pure ecosystem approach would surely result in the extirpation of many large animals and probably many small plants and animals as well.

To demonstrate the interdependency of the three approaches, I suggest that the following questions be considered:

1. *For the vertebrate and endangered species chauvinists:* What ecosystem processes and landscape elements or habitats are necessary for the viability of your species, and how should these processes and elements be distributed in space?

2. *For the ecosystem and plant community classifiers and gap analysts:* What animals are necessary for the formation of gaps, dispersal of propagules, pollination, turnover of nutrients, and prevention of competitive exclusion (where herbivore populations are too low)?

3. *For the ecosystem process ecologists:* How do you determine how much wetland, old growth, sea grass, reef, mud flat, ocean, etc. is necessary to provide the resources to maintain viable populations of the species in the highest tropic levels in this and associated ecosystems?

In other words, it is no more possible to protect biodiversity by blindly focusing on numbers of individuals than it is by blindly focusing on plant community representation or nutrient flows, net primary productivity, or resilience. Sometimes the flurry of jargon and paper often obscures what good biologists know. Good biologists know these things, but sometimes our rhetoric becomes so rarefied that its connection to its ecological substrate is severed.

The essential point is that the dualism of organism and environment is a dangerous blasphemy against ecology. The science of ecology, having been artificially and harmfully split for decades between ecosystem ecologists and population–community ecologists, shows signs of wearying of the divorce. Let us hope that the reconciliation can occur in conservation biology before more damage is done.

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The Need for Ecosystem Vital Signs

Winifred B. Kessler

The usual way of thinking about biological diversity is as the variety of organisms that exists within an area of interest or management jurisdiction—hence the use of species richness and other "species-counting" indices to describe the diversity within an area of interest. Although I have used such indicators in my own research in the past, I have problems with them that I will not go into here but that are treated elsewhere (e.g., Kessler 1993).

We know that biological diversity is much more than can be revealed by a count of species. It includes the complex pathways and processes that link organisms one to another and to the environment, their genetic composition, and the processes that sustain the whole as dynamic, self-regulating systems. My thesis is that in developing indicators for the ultimate purpose of conserving biological diversity, we need to expand our traditional focus on species to the ecosystem level and landscape scale. I hold this view for very practical conservation reasons that are considered later in this paper. First, we need to answer an important question.

Species versus ecosystems?

Does advocating more emphasis at the ecosystem and landscape levels suggest that we abandon species-focused work? Absolutely not! I can sympathize with what conservation biologist Michael Soulé perceives to be "species bashing," but fortunately my experience has been very different. In my own work in conservation planning, much of it with land management agencies and conservation organizations, I have not encountered people who seriously consider this an either/or question. This is just so illogical a notion that to most it is a nonissue.

There are some very important reasons why we must continue to focus on species. One is that society genuinely values some species more than others and demands that we invest public and private resources accordingly in assuring their survival. Second, from a conservation standpoint, species-focused attention is our only recourse for organisms in a perilous state. As well, the approach is tried and true, having prevented several species from going over the brink of extinction.

But we also know that, by itself, the species approach is insufficient as a conservation strategy for biological diversity. The sheer number of species makes that impossible; we could never focus attention on them all. Many of them are simply not accessible for study: for example, the vast assemblages of organisms that live below the ground. And a narrow focus on an individual species can blind us to the big picture of why not only that species but also suites of others are declining in response to some process disruption at the ecosystem or landscape level (my examples later will go into this).

Preventative health for people and ecosystems

I think we are finally arriving in the arena of "ecosystem health," where human health has already been for several decades. In our grandparents' time and before, seeking medical attention was something you did only if you were sick or injured. Attention could then be lavished on the troubled organ or body function, in hope of arresting or curing the disorder before the patient died.

Astute doctors came to realize, however, that many ailments could be avoided in the first place by preventative medicine aimed at healthy rather than sick people. As you know, preventative medicine includes regular checks on an individual's health, using practical indicators (e.g., blood pressure, cholesterol level) to signal any problems. If found, these can be treated early through corrective measures and followed more closely.

Our approach to species conservation has a similar history. Species gained our attention and efforts only after they were in trouble, or even "near death" in the case of threatened and endangered species. Does this mean we now refuse to treat those species? As in human medicine, that would not be appropriate at all. But also as in medicine, we need a preventative emphasis aimed at detecting systemic troubles early so that corrective measures can be undertaken.

Vital signs for ecological health

I suggest to you that this is a major task we should be about in our jobs as scientists, conservationists, and resource managers: developing indicators of ecosystem health aimed at early detection and prevention. We need to detect system-level problems before they manifest themselves in declines of individual species. I like to think of these as vital signs for ecosystem health, comparable with the vital signs used in human health. These would serve as "red flags" to warn of possible problems and also allow monitoring through time and in response to treatments.

Might some of those vital signs be directed at species—for example, their population levels, genetic composition, or vigor of individuals? Probably yes. Although not fully validated, the idea of species as ecological indicators still sounds reasonable enough. But species alone will not suffice. We must direct a great deal more attention to indicators that may warn us of problems in overall system process or function.

Why do I believe the emphasis should be on process and on the larger (landscape and ecosystem) spatial scales? These biases come from my own experiences and observations, which lead me to believe that these levels often offer the greatest returns in conservation investment. I will share a few examples, so if you are not convinced at least you can understand my biases!

Example 1: Prairie dynamics and the Attwater's prairie-chicken

I will begin with my doctoral research of some 20 years ago. Prior to starting it, I had worked for Dr. Harold Biswell at the University of California at Berkeley, who was then called a "raging pyromaniac" but is now recognized as a pioneer in fire ecology and management in California. In shaping my ecological background, the work in fire ecology had definitely given me an appreciation for process and dynamics. After leaving Berkeley, I undertook at Texas A&M University what had been described as an endangered species project. The species was the Attwater's prairie-chicken *Tympanuchus cupido attwateri*, and people were doing everything they could think of to try to reverse or stabilize its population decline.

Everyone generally recognized that habitat loss was the root of the prairie-chicken's problem. Most of the coastal prairie (a tallgrass ecosystem) had been converted to rice cultivation and other uses. One of the remaining tracts had been purchased by the

Nature Conservancy and fenced off, people and cows had been removed, and protection was strictly enforced. But, alas, the birds continued to decline.

When I arrived, the problem was clear: the bird continued to decline because the tallgrass prairie, of which the bird was an integral part, was seriously deteriorating in spite of (and in fact because of) the strict protection. As with all tallgrass prairies, this dynamic ecosystem had evolved with and was sustained through time by fire and grazing. When these vital processes were disrupted, the system began its steady decline.

My study focused on prescribed fire and grazing regimes to restore the prairie, and in that it was quite successful. The dividends included hosts of plant and animal species that, although not endangered like the Attwater's prairie-chicken, had likewise declined as the system went downhill. What about the prairie-chickens themselves? Unfortunately, they are a classic example of a small, fragmented population that is "winking out" in spite of heroic conservation efforts on their behalf. At last count, there remained only 28 males displaying on the refuge. Despite this failure, a great deal was learned about prairie dynamics—and with that, promise to conserve a great many species through a focus on process, ecosystems, and landscapes.

Example 2: Disappearing flowers in the Shawnee National Forest

Perhaps an even better example is one from the Shawnee National Forest in Illinois, where a major issue is the decline and disappearance of numerous wildflower species from the forest. For several years, the usual approach had been taken on this problem. U.S. Forest Service botanists would search the forest until they found individuals or clumps of the disappearing species. They would flag the area, map it, and establish a "no disturbance" zone to protect the plants. After several years of this intensive effort, however, the plants failed to respond.

Then a new botanist named Larry Stritch joined the Shawnee, with a recently completed Ph.D. that encompassed plant ecology as well as botany. He took a look around and gave his professional opinion that all the loving protection being lavished on the various species was actually hastening and ensuring their disappearance. What all these species had in common, he observed, was that they were not "forest" flowers at all. They were prairie species and were dying out because the landscape components they were part of, prairie openings, were disappearing from the Shawnee

National Forest. Why? Because there was great public opposition to logging on the Shawnee National Forest, and thus very little was being done.

Larry managed to restore thriving populations of these species by cutting small patches in the forest and running fires through them. The hardest part was in public relations: educating people about the true reasons for declining diversity and getting their acceptance of tree harvest and fires as the means for reversing the declines. But response was instantaneous. The first season after the burn, there were prolific blooms of species that people had not seen in flower for 40 or 50 years.

Final example: Goshawks in southwestern forests

I will close by emphasizing again that the species versus ecosystem notion is a false dichotomy. In developing indicators and conservation strategies, we need to look at all levels, from genes to ecosystems, and at processes as well as components. In fact, starting at one level, say species, will very likely lead you full circle to ecosystems. I offer one final example to illustrate this point: the goshawk conservation strategy for the southwestern United States.

Because goshawk populations are declining throughout forests of the southwest, an interagency committee was established recently to develop habitat conservation guidelines for the species. The committee was instructed to take a species-focused approach, addressing just those habitat conditions required by goshawks in southwestern forests.

The committee began with a conventional approach. It determined the kind of forest stand conditions needed by nesting goshawks, for purposes of establishing protective "buffers" around existing and potential nest sites. However, critics quickly pointed out that nest sites do not equate with goshawk population viability. The birds have other vital requirements—for example, suitable hunting habitat with healthy populations of prey.

So the committee broadened its approach. It began by identifying the major dietary items of goshawks in the southwest and then initiated an investigation of the habitat needs of these prey species. This line of investigation led to the finding that declines in goshawk prey and prey habitat, and subsequently in goshawks, were related to the declining health of pine ecosystems throughout the southwestern United States. This, in turn, was a consequence of fire exclusion policy and certain management practices of preceding decades. The committee's conclusion?: that the best way to restore conditions needed by the goshawk and its various prey species was to restore the processes that are vital to the health and dynamics of the southwestern pine ecosystems.

In essence, the committee had come full circle. It had begun by focusing on a single species, but this had brought it around to an ecosystem approach. And this is as it should be. Ecosystems and species are inextricably linked. It is meaningless to advocate species conservation without addressing the ecosystem that is the context for a species' existence, just as it is meaningless to advocate ecosystem health without recognizing species as the very "fabric" of those systems. What goes around comes around.

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Monitoring Implications of Forestry-Related Activities on Biodiversity in British Columbia

Evelyn Hamilton

A system for monitoring changes in biodiversity in response to forestry-related activities was developed by this workshop. The components of the monitoring system include drivers or agents of change and response variables. I have used this framework to report on the availability of information that is being used or could be used to monitor biodiversity in British Columbia (Table 1). Some of this information is summarized in the *State of the environment report for British Columbia*, which provides a good overview of the availability of environmental monitoring information in the province and summaries of some data (B.C. Ministry of Environment, Lands and Parks and Environment Canada 1993). Additional information on elements of biodiversity in British Columbia is available in Rautio (1991), Fenger et al. (1993), and Harding and McCallum (1994). A selected number of publications that provide more detailed information are referenced in Table 1.

Some of the system drivers that were recommended for monitoring by the workshop are directly linked with forestry activities, whereas others are more indirectly related. The direct drivers include:

- the areal extent of logged and roaded land;
- the frequency and areal extent of fire and insect and disease outbreaks;
- the areal extent of productive forest land: and
- the forest harvest level.

The B.C. Ministry of Forests Annual Reports provide this information (B.C. Ministry of Forests 1991). Information on some of these drivers has been recorded since about 1913 (Table 1). Data bases on insect and disease outbreaks date back to 1921. Other system drivers (not included in the workshop's model) such as extent of reforestation and area protected can also be reported on by ecological area (B.C. Ministry of Forests 1991; Eng 1992).

Table 1. Status of information on drivers and response variables relevant to monitoring implications of forestry activities on biodiversity in British Columbia.

Attribute	Information available	General data source[a]	Some specific publications[b]
Drivers			
Area logged by ecological area	Area by land tenure, by harvesting method, by region	MoF Inventory Branch MoF Timber Harvesting Branch	1, 2
Roaded land type, density, effect on wilderness quality	Roaded areas—% by ecological area	MoF Recreation Branch	3, 4
Forest harvest level by ecological area	Rate of harvest since 1913	MoF Inventory Branch	3
Fire and insect disturbance regimes			
area	Area (ha) disturbed/ year since 1921	MoF Protection Branch	3
frequency	Fire—no./year since 1913	MoF Protection Branch	3
	Insects—outbreaks since 1921	CFS	3
amplitude	Derived from above information		
Measures of water quality and quantity	Stream flow for some rivers	MoELP Hydrology Branch Environment Canada	5
	Water quality for selected sites	MoELP Water Quality Branch Environment Canada	
Changes in soil productivity	Agricultural land capability	MoELP Lands Division	1
	Area of productive forest land, by region	MoF Inventory Branch	2
Measures of climatic change	CO_2 levels	AES	6
	Temperatures back to 1895	AES	7, 8
Measures of stress (e.g., pollutants)			
acidic deposition	Some sites since 1985	MoELP Air Quality Branch, AES, CWS	9–13
toxins in wildlife	Information for some aquatic species		
Response variables			
Indicators for rare, threatened, endangered, and vulnerable species	Lists of vascular plants and vertebrates	CDC, RBCM	14
	Status reports for some species	COSEWIC, CWS, CDC	15, 16
	Limited information for other species		17–20
Landscape and patch measures of composition, structure, and configuration			
landscape composition, pattern	Satellite images, air photos, forest cover, biophysical habitat maps	MoF Inventory Branch, MoELP	21

(continued)

Table 1. *(continued)*

Attribute	Information available	General data source[a]	Some specific publications[b]
patch (forest cover polygon)			
composition	Tree species composition, age	MoF Inventory Branch	21
structure	Number of layers, crown closure	MoF Inventory Branch	21
configuration	Polygon shape		
Patch (biophysical habitat unit)	Biophysical habitat type descriptions	MoELP Wildlife Branch, MoELP Habitat Inventory	22

[a] Acronyms used:

AES	Atmospheric Environment Service, Environment Canada
CDC	Conservation Data Centre (MoELP)
CFS	Canadian Forest Service
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CWS	Canadian Wildlife Service, Environment Canada
MoELP	B.C. Ministry of Environment, Lands and Parks
MoF	B.C. Ministry of Forests
RBCM	Royal British Columbia Museum

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A limited number of data on other more indirect drivers (i.e., water and air quality, water quantity, climatic conditions, and levels of toxins in wildlife) are also available (Table 1). Monitoring of water quality and quantity has occurred in a limited number of sites. Long-term water quality monitoring stations have been established fairly recently. Levels of toxins in some marine environment species are monitored (e.g., seabirds, fish, invertebrates).

A summary of the status of information on species presence and population levels is provided in Radcliffe and Porter (1992b). The report includes information on the type of data available, the period of data collection, strengths and weaknesses of the data, and available data formats. The distribution of bird species, particularly game birds, diurnal birds of prey, and water birds, and large mammals, particularly game species, is generally better known than is the distribution of other vertebrates and invertebrates. Distributions of amphibians, reptiles, and bats, shrews, moles, and other small mammals are poorly known, with almost no information for some species. Vascular plant species distributions are better known than are those of nonvascular plants, fungi, and lichens. Information on distributions of invertebrates and fungi, except for those of commercial importance (e.g., forest pests), is fragmentary to nonexistent (Ryan et al. 1993; Gordon and Hamilton 1994; Scudder 1994). Compilations of information on elements of biodiversity in some regions of the province are also available (Radcliffe and Porter 1992a; Radcliffe et al. 1994).

Population trend monitoring has been done for a limited number of species (primarily large mammals and birds) (Table 2). Some of the methods used are outlined in Ramsay (1992). Methods for sampling a variety of species and species groups are being standardized by the Resource Inventory Committee (e.g., Winchester and Scudder 1994). Many of the existing population data come from hunting and trapping records and road kill statistics and are therefore not unbiased or comprehensive. More complete population surveys are done for some species, particularly game animals. Nest survey records and sight

Table 2. Status of monitoring activities for species groups in British Columbia and key provincial data sources.[a]

Groups	Information on distribution	Source of population monitoring information[b]	Key provincial data sources[b,c]
Mammals			
large mammals	variable	road kills, hunter records	MoELP, RBCM
ungulates	very good	range and areal survey	MoELP
grizzly bear	good	research, hunter records, range surveys	MoELP, MoF
furbearers	good	trapping records, research	MoELP, MoF
other small mammals	variable	research, forest and agricultural damage surveys	MoELP, MoF
shrews, bats, moles	poor	research	MoELP, MoF
Birds			
game birds	very good	surveys	MoELP, CWS
coastal water birds	very good	surveys	MoELP, CWS
birds of prey	variable		MoELP, CWS
bald eagles	very good	nest surveys	MoELP
gyrfalcons and peregrine falcons	very good	nest surveys	MoELP
all breeding birds	good	nest records	FBCN, RBCM, CDC
all birds	good	sight records migratory species monitored	FBCN, RBCM, CDC CWS
Amphibians and reptiles	fair	IUCN monitoring	RBCM, CDC
Invertebrates			
forest pests	good	FIDS	CFS
other species	very poor		RBCM, CDC, UBC
Vascular plants	good		RBCM, CDC
Nonvascular plants, fungi, lichens			
nonvascular plants	very poor		RBCM, CDC, UBC
fungi	good	FIDS	CFS, MoF
forest pests	very poor		MoELP
other species	very poor		UBC, RBCM, MoELP
lichens	very poor		UBC, RBCM, MoELP

a Information derived primarily from Radcliffe and Porter (1992b).

b Acronyms used:

FBCN Federation of British Columbia Naturalists
FIDS Forest Insect and Disease Survey
IUCN International Union for the Conservation of Nature and Natural Resources
UBC University of British Columbia.
See Table 1 for other acronyms.

c There are also a number of national data sources for these species groups.

records are available for breeding birds, with more complete information on game birds, water birds, and birds of prey. Monitoring of invertebrates and fungi is restricted to those of known economic concern (e.g., pest species). The Conservation Data Centre of the B.C. Ministry of Environment, Lands and Parks monitors vascular plant and vertebrate species at risk (e.g., Red list species). Research is also under way on a number of species to provide an indication of population trends and to better understand their habitat requirements (Hamilton 1994).

Forest cover data, air photos, and satellite images, which can be used to describe landscape patterns, are also available. Forest cover information including dominant tree species, stand age forest structure (layer), and crown closure is housed in the B.C. Ministry of Forests inventory data base. Biophysical habitat mapping is also available for many parts of the province (Harper et al. 1993; Demarchi 1994). The Resource Inventory Committee is revising existing inventory methods to develop an integrated inventory system that will be useful for biodiversity monitoring purposes (Vegetation Inventory Working Group 1994). Information on the genetic diversity of major forest tree species is available; however, there is little information on other trees or other species (Lester 1993; Yanchuk 1994).

In general, although there is some information that can be used to determine changes in drivers and response variables over time, a more comprehensive system is required to adequately monitor changes in biodiversity related to forestry activities in British Columbia.

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Forest Biodiversity Assessment and Monitoring in the Maritimes

Judy Loo

In the Maritimes region, as elsewhere, requirements for biodiversity-related information greatly outpace the current availability. To conduct meaningful biodiversity monitoring, baseline data must be in existence. Although potentially useful data have been collected for various purposes over the years, the task remains to identify and collate those data of real value in providing a biodiversity baseline. In addition, new initiatives are imperative to fill the present knowledge gaps.

Forest managers and researchers in the Maritimes region are responding to the escalating concern over biodiversity in a variety of ways. Existing data bases are being evaluated for usefulness of biodiversity-related information or modified to increase usefulness. New data bases are being developed, particularly in connection with the Fundy Model Forest. Strategizing and planning for systems of protected natural areas are receiving much greater emphasis than previously in both New Brunswick and Nova Scotia. In New Brunswick, there is also an effort under way to explicitly include biodiversity considerations in Crown land management.

The following is a brief overview of some of the data bases and management and research initiatives that are expected to be useful in assessing forest biodiversity in the Maritimes. It is not intended to be an all-encompassing list.

Data bases

Forest Insect and Disease Survey (FIDS) data bases

Three kinds of information have been stored in FIDS data bases in the Maritimes region. A light trapping system with permanent plot locations has supplied more than 20 years of standardized data on more than 60 moth species (more than 70 species since 1990). The number of permanent sampling locations has steadily declined in recent years, with present plot locations restricted to three national parks.

A second type of information has been collected at condition appraisal points (CAPS program), which have a systematic distribution in time and space. In any given year, sampling locations are scattered across the Maritimes region, and the locations change from year to year so that, over time, any geographic area will be thoroughly sampled. At these points, all insect and disease pests are identified on primary host tree species, and associated data such as stand descriptors are collected and stored as well.

The all-encompassing data base known as the "FIDS Database" is a conglomerate of information acquired since 1936 using various sampling methods and levels of detail. It is likely that information contained in this data base could be useful for providing a biodiversity baseline; however, the data were not collected with that purpose in mind, so caution must be exercised in extrapolation.

Atlantic Region Conservation Areas Database (ARCAD)

Protected natural areas, particularly when designed to represent major ecosystem types, may be important sources of biodiversity baseline data, as well as monitoring sites for the future. Effective use of such areas requires knowledge of the biodiversity that is protected by them.

The Atlantic Region Protected Areas Working Group, consisting of representatives from three federal agencies—Environment Canada, Parks Canada (Heritage Canada), and Natural Resources Canada—have modified and expanded Environment Canada's National Conservation Database for the four Atlantic provinces. The ARCAD is maintained by the Canadian Wildlife Service in Sackville, New Brunswick. The data base includes information about size, level of protection, ownership, managing agency, and other administrative-type information, as well as information on the important biological features for each protected area (as far as they are known) and the natural region and ecoregion in which it occurs.

It is expected that the data base will be useful in planning habitat conservation, tracking the level of existing protection, setting protection goals, measuring progress, assessing environmental impacts, and planning biodiversity research and monitoring in the region.

Conservation Data Centre (CDC)

None of the Atlantic provinces currently has a Nature Conservancy Conservation Data Centre. Discussion and negotiation have been under way for the past year to assess the potential for establishing one or more CDCs in the Atlantic provinces. The need has been identified, a steering committee has been struck, and a number of options have been developed.

If the center becomes a reality, it is expected that it will provide a focus for the compilation of existing information currently existing in universities, provincial nature museums, and other institutions that collect and store information on the Atlantic region's biota. In addition, it is expected that a standardized mode for collection of new data will be adopted and implemented, improving the quality of data available for many parts of the Atlantic provinces.

Biodiversity assessment initiatives

Fundy Model Forest

In New Brunswick, the Fundy Model Forest has provided a focus for a number of new biodiversity-related initiatives, each of which involves collecting data at some scale. The Fundy Model Forest is a 400 000-ha, primarily forested, area. More than half of the forested area consists of small private woodlots. The model forest also includes Fundy National Park, and the remainder of the area is almost equally divided between provincial Crown and industrial freehold lands.

Projects under way in the Fundy Model Forest include comparing biodiversity of various taxa at the genetic, species, and structural levels between natural and silvicultural forests; assessing the viability of older-growth forest communities; and evaluating the relationship between intensive forest management and cavity-nesting birds. These studies will contribute data on the natural biodiversity of forests and how it is changed by contemporary forest practice. For some of these studies, there is a time dimension, with comparisons made among stands of different ages that are as ecologically and silviculturally similar as possible, constituting a chronosequence.

A vegetation-based ecological land classification is being conducted in the Fundy Model Forest at a relatively fine scale, which, among other things, is intended to be useful in estimating the expected natural levels of biodiversity under given sets of abiotic conditions. In addition, a gap analysis is being conducted to inventory and catalog major ecosystem types, rare and sensitive species and habitats, and centers for species richness. It will be determined whether these ecological features are currently represented in protected natural areas, and strategies will be recommended to ensure their long-term viability. Both these projects are designed not only to provide information on the specific land area constituting the model forest, but also to develop protocols that can be applied to other parts of the region.

An insect biodiversity project is under way that has as one goal the establishment of monitoring protocols for some species currently supposed to be indicators or to have ecological significance.

New Brunswick Forest Biodiversity Assessment

A project is under way in New Brunswick to develop a working definition of biodiversity from a forest management perspective, which can be used to project the impact of the implementation of the current management plans on stand level biodiversity of the upland forest. The assessment is being done using the province's ecological land classification, which is concurrently being developed. The future distribution of ecological site types, stratified by age class and landscape unit, will be estimated for the sequence of harvests and silvicultural treatments as they are identified in the management plans. In addition, future landscape patterns will be evaluated with a spatial dimension.

The purpose of the assessment is to identify any combinations of ecological site type (forest type) and age class in a given landscape unit that can be expected to decline significantly as a result of the implementation of management plans. Concurrent initiatives, providing information essential to this assessment, are ecological descriptions of each landscape unit in the province at each level of the ecological land classification hierarchy, development and validation of successional models for each vegetation community, and development of an age class map for the province.

Representation of major Acadian forest types in protected areas

A study was undertaken in summer 1993 to assess how well the major forest types of the Acadian Forest Region are currently represented in highly protected natural areas. The Acadian Forest Region covers most of the Maritime provinces and is a transitional forest between boreal coniferous and temperate hardwood forests. Sixteen major forest types were identified, and the area of each was assessed in the region's highly protected natural areas. Several forest types are seriously underrepresented, including floodplains, mixed coniferous and deciduous late-successional, and cedar–hemlock forest types. The types with poorest representation are also those with greatest pressures and threats outside of protected areas. Periodic assessments such as this will assist in monitoring forest ecosystem viability in the region.

Conclusion

Biodiversity monitoring is problematic because of the breadth of the topic. It spans scales from genetic to landscape, with each scale requiring a completely different set of tools and expertise. Within each of these levels, the questions are large and complex, and often our understanding falls short of that needed even to identify appropriate measures. While we conduct the research needed to make informed choices of indicators of biodiversity at the various scales, we cannot afford to wait for the answers, but we must measure those things that make sense, adding or dropping measures as better information becomes available. In the Maritimes region, we are attempting to balance our activities between the immediate, pragmatic, and longer-term research in such a way that options will not be closed as we gain knowledge over time.

Ontario's Genetic Heritage Program

Dennis Joyce

There are four major forest zones in Ontario. From south to north, these zones are Carolinian, Great Lakes–St. Lawrence, Boreal, and Barrens. The general level of human impact on genetic variation of native tree species varies among these zones. The Carolinian Forest is highly fragmented as a result of agriculture and urbanization. As a result, the genetic integrity of species and populations is suspect. The Great Lakes–St. Lawrence Forest has sustained more than one cycle of harvest. In some cases, harvests have been selection cuts of preferred species that may have resulted in at least low-level fragmentation and some genetic erosion of some species. The Boreal Forest is generally sustaining only the first cycle of harvest. Although species diversity is limited, most species are relatively abundant in the landscape. There is little expectation of significant levels of fragmentation. The Barrens Forest is largely in a natural state.

Genetic variation is often viewed as a fine-scale level of biodiversity. For example, biodiversity is sometimes treated as a hierarchy of ecosystem, species, and genetic variation. This view of genetic variation ignores the complex structure and function of genetic variation at the ecosystem, species, and population levels. The persistence of species within ecosystems is a function of vigorous growth and fecundity, which results from the interaction between the genetic constitution of individuals, populations, species, and the environments in which they occur. Thus, genetic variation is more appropriately viewed as an attribute of biodiversity, rather than a scale. As such, it is one of the primary resources (air, water, soil, and genetic variation) requiring management. Because of the dynamic role genetic variation plays in plant vigor, fecundity, host/pathogen interactions, interspecific competition, and adaptation/evolution, the concept of preservation of a given state of genetic diversity has limited application. Rather, the focus of genetic resource management should be the retention of evolutionary capacity.

The Genetic Heritage Program

Because it is difficult to directly observe genetic composition, structure, and functioning in forest trees, genetic resources are vulnerable to degradation when not explicitly considered in landscape management decisions.

In 1989, the Government of Ontario funded the Sustainable Forestry Initiative in response to concerns regarding sustainable forest management. As part of the Sustainable Forestry Initiative, the Genetic Heritage Program is mandated to develop species conservation strategies and to develop policy and management guidelines that address gene conservation, genetic diversity, and the retention of evolutionary capacity.

Species management plans

In most cases, species management plans will be focused on maintenance rather than restoration. In Ontario, maintenance-oriented species management plans are based on two principles. The first is that natural populations within species are adaptively differentiated when they occur in different climatic conditions. As a result, conservation of adaptive gene complexes is a priority. Strict adherence to Ontario's climatically based system of seed zones addresses the conservation of adaptive gene complexes. The second principle is that the retention of evolutionary potential requires large effective population sizes (at least 1000 individuals). For management purposes, the number of individuals within a seed zone is considered to be a "population." Management plans for individual species will be based on their status within individual seed zones.

Restoration strategies are oriented towards species that are vulnerable to extirpation or extinction, primarily as a result of forest fragmentation and small population sizes. Restoration strategy priorities include:

- protecting existing individuals;
- fostering vigorous offspring by limiting the effects of inbreeding depression;
- estimating effective population size as a basis for consideration of the need for reintroduction to increase an impoverished genetic base; and
- increasing population sizes to the point where they are evolutionarily viable.

The Genetic Heritage Program is actively developing species priorities, both provincially and regionally. A process for developing species management plans has been developed and implemented for priority species. Because of the severe level of forest fragmentation, most priority species are associated with the Carolinian Forest zone.

The process of developing species management plans consists of five general steps:

- identify the biological characteristics of individual species, i.e., geographic range, habitat specificity, and characteristic population sizes;
- identify current distribution and population sizes;
- develop a prognosis by comparing current condition with biological characteristics to provide an estimate of species condition (intact, eroded, threatened) and primary risk factors;
- develop a strategy for restoration or maintenance depending on population size, demographics, and spatial distribution; and
- develop implementation plans on a seed zone basis.

Studies in genecology

A genecological research project has been initiated to identify adaptive strategies of priority species in Ontario. Short-term testing procedures are being used to identify levels of population differentiation in phenology, cold hardiness, and growth potential. Models are being developed that describe the spatial patterns of adaptive variation. Such models are viewed as critical baseline information for efficient management of seed and stock transfers and for addressing climate change concerns. Studies in progress include black spruce, jack pine, white spruce, and red oak. Additional studies on species such as eastern white pine and red pine are anticipated.

Bio-Environmental Indices Project

Genetic Heritage Program funding has provided partial support to the Bio-Environmental Indices Project, led by Drs. Brendan Mackey and Dan McKenney at the Great Lakes Forestry Centre. The project is developing a digitized elevation model for Ontario as well as a geographic information system (GIS)-related data base of climatic variables. Climatic modeling software developed in Australia by Dr. Mackey and his colleagues has been adapted for use in Ontario.

The recently completed climatic model has already proved useful for evaluating bioenvironmental relationships, especially in the analyses of the genecological data base. Using the model, population differentiation in growth potential and phenology of black spruce is closely associated with growing season length. The climatic model is also being used to develop climatically based seed zones for the province.

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Appendix 2: Workshop Agenda

Day 1 — Monday, November 29, 1993

9:00	**Greetings** Carl Winget, Director General Canadian Forest Service–Ontario
9:10	**Introductions and Workshop Process** Jim Farrell, Workshop Chairman Canadian Forest Service–Ontario
	Policy Context for Indicators
9:30	**National Forest Strategy** Ole Hendrickson Canadian Forest Service, Ottawa Harry Hirvonen State of the Environment Reporting **National Biodiversity Strategy** Dave Gordon Ontario Ministry of Natural Resources
10:30	Coffee Break
11:00	**Canadian Forests and Current Forestry Practices** Paul Addison and Richard Sims Canadian Forest Service–Ontario
11:30	**A Biological Conservation Perspective on Forests** Daniel Welsh Canadian Wildlife Service
12:00	Lunch
1:00	**Review of Draft Focus Paper (DFP)** Brendan Mackey Canadian Forest Service–Ontario
1:45	**Participants' Comments on DFP and Position Statements on Candidate Biodiversity Indicators** (roundtable format)

3:00	Coffee Break
3:15	**Roundtable Continued**
5:00	Finish
7:00	**Algo Club:** Workshop Dinner After-Dinner Presentation: Gary and Joanie McGuffin: "Adventures across Canada"—slide presentation of Trans-Canada canoe and bicycle expeditions

Day 2 — Tuesday, November 30, 1993

Species-Based Indicators

8:30	**Review of Session Format and Distribution of Candidate List of Species-Based Indicators**
8:40	**The Need for a Species-Based Approach to Ecosystem Management** Michael Soulé Chair, Environmental Studies, University of Santa Cruz
9:10	**Break-Away Group Discussion on Species-Based Indicators**
10:00	"Working" Coffee Break
10:15	**Group Reports**
11:00	**Roundtable Synthesis**
12:00	Lunch

System-Based Indicators

1:00	**Review of Session Format and Distribution of Candidate List of System-Based Indicators**
1:10	**The Need for Indicators of Ecosystem Vital Signs** Winnie Kessler Chair, Forestry, University of Northern B.C.
1:40	**Break-Away Group Discussion on System-Based Indicators**
3:00	"Working" Coffee Break
4:00	**Roundtable Synthesis**
5:00	Finish

Day 3 — Wednesday, December 1, 1993

Plan of Action—Recommendations

8:30 **Review of Indicator Short-List and Scientific Rationales**

9:00 **Examples of Biodiversity-Related Data Bases, Surveys, and Monitoring Programs in Canada**

- Evelyn Hamilton, Resource Ecologist, Integrated Resource Management, B.C. Ministry of Forests
- Judy Loo, Research Scientist, Canadian Forest Service–Maritimes
- Dennis Joyce, Forest Geneticist, Ontario Forest Research Institute
- Margaret Penner, Research Scientist, Petawawa National Forestry Institute
- Henry Nix, Director, Centre for Resource and Environmental Studies, The Australian National University

10:00 Coffee Break

10:15 **Assessment of Required Data and Data Availability**

12:00 Working Lunch

1:00 **Plan of Action**

- Requirements to better utilize existing data
- New initiatives

2:30 **Review of Final Recommendations and Workshop Synopsis**

3:00 **Closing Comments**

Appendix 3: Related Literature

During the course of preparing the focus paper for this workshop, a preliminary listing of biodiversity-related articles was compiled. This collection is not definitive, but it does represent an eclectic coverage of the subject and clearly indicates that there is a wide variety of published materials on the general topic of biodiversity. For presentation purposes, the listing has been divided into two general categories: *Ecology and biology*, and *Economics and management*.

Ecology and biology

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