Conceptual framework and rationale for monitoring forest biodiversity in Alberta

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Abstract

The Alberta Forest Biodiversity Monitoring Program represents an attempt by natural resource managers to build a comprehensive, long-term monitoring program that will measure success towards the goal of sustainable development in Alberta's forests. Such a program would confer strategic advantages to the forestry and energy sectors, and would contribute to the reporting mandate of National Parks and other protected areas. While there are few examples of successful ecosystem-based monitoring programs, suggestions from the literature provide some guidance, including clearly stated objectives, careful identification of stressors and indicators, and a well-defined but flexible implementation plan. Preliminary lists of 12 stressors and 19 indicators of biodiversity are proposed for monitoring in Alberta at multiple resolutions, using remote sensing technologies and field sampling protocols in aquatic and terrestrial systems. Cost-effectiveness, relationship to stressors, and level of biological organization are important criteria for refining this preliminary list of indicators. Because it is difficult for a single system to satisfy multiple objectives, an integrated framework for monitoring forest biodiversity is proposed that is based on four related monitoring levels: Provincial Trend monitoring, Regional Trend monitoring, Large-scale Management Experiments and Long-term Ecological Research sites. The current emphasis of the Alberta Forest Biodiversity Monitoring Program is on Regional Trend monitoring, with alternative scenarios for site density, measurement frequency, and sampling effort evaluated in the context of statistical power to detect trends.

Introduction

The Alberta Forest Biodiversity Monitoring Program represents an attempt by natural resource managers to build a comprehensive, long-term monitoring program that will measure success towards the goal of sustainable development in Alberta's forests. The program is multi-sector, provincial in scope, and will assist the strategic positioning of participant companies and government agencies facing increasingly sophisticated consumers and citizens requesting objective, current, and scientifically credible information on ecosystem health.

The forest ecosystem provides the natural capital on which Alberta, a major exporter of forest and petroleum products, depends for much of its economic and social prosperity. As the cumulative effects of growth in the forestry and petroleum sectors continue to grow, concerns over ecosystem health will also continue to increase both in Alberta and beyond. Without a mechanism to monitor forest biodiversity, neither government nor private sector natural resource managers will be in a position to respond to serious public scrutiny. Assisting these sectors in their efforts to maintain and enhance public confidence and market security is a high priority for both government and industry, and will benefit all Albertans.

The goal of the Alberta Forest Biodiversity Monitoring Program is to develop, test, and evaluate a long-term monitoring program capable of detecting changes in the biodiversity of Alberta's forests. When implemented, a selection of aquatic and terrestrial plant and animal species, and the assemblages, communities, and landscapes in which they live, will be monitored in a coordinated fashion across Alberta's forests over several decades. Success in generating and maintaining the commitment of resources for long-term implementation requires considerable initial investment to ensure that the program develops into one that is developed is both scientifically sound and practical.

Development of the program is guided by several principles:

- The program should support existing commitments (local, national, and provincial) for biodiversity monitoring.
- Monitoring should use a common, standardized methodology applied across the entire area of interest (Alberta's forested natural regions).
- Monitoring should occur in both aquatic and terrestrial systems; an integrated approach is preferred.
- Ecosystem elements that represent life forms from diverse taxonomic groups and trophic levels should be monitored.
- Monitoring should occur across hierarchy of spatial scales.
- Monitoring should occur in locations having a wide range of land use histories, including those with limited human influence (i.e., reference areas).
- The program should include mechanisms to estimate natural variability to assist interpretations of the significance of observed changes.
- The program should be transparent in development and implementation.

Starting assumptions

The establishment of a successful environmental monitoring system that records the status and trends of forest biodiversity in Alberta would require resources directed towards data collection across a large area (hundreds of square kilometers) and over a long time period (several decades). While numerous arguments support the strategic benefits of such a system (see below), certain starting assumptions must be accepted:

1. Biodiversity is the variability among living organisms and the ecological systems in which they participate. Variability among living organisms is observable at multiple scales and levels of biological organization.
2. Biodiversity has economic, social, and spiritual value for present and future generations of Albertans.
3. Changes in biodiversity occur as a result of natural resource management, although the complexity of ecological systems often makes it difficult to relate a particular management activity to a particular change in biodiversity.
4. The extent and magnitude of natural resource management in the forested portion of Alberta will continue to increase over the next several decades.
5. Certain changes in biodiversity are observable only when considered over appropriate spatial and temporal scales. Some significant changes are observable only when considered across the entire province and over one or more decades.
6. Certain changes in biodiversity, such as range reductions, will be viewed as detrimental by persons with a legitimate interest in the biodiversity of Alberta. Other changes, such as increases in the abundance of game species, will be viewed as beneficial by persons who also have a legitimate interest in the biodiversity of Alberta.
7. An improved mechanism for monitoring biodiversity in Alberta will increase the ability of persons and organizations with natural resource management responsibility to fulfill that management responsibility.

Strategic benefits of environmental monitoring in Alberta's forested regions

Support the Alberta Advantage

The economy of Alberta is driven by three primary industries: energy, agriculture, and forestry, with additional contributions from manufacturing and advanced technology. Much of the energy industry, and all of the forest industry, is situated in the forested portion of Alberta, which covers approximately three-quarters of the province's total area of 664,000 km^2. In the fiscal year

1997/98, government royalties from the sale of natural gas and conventional oil were $1.6 billion and $900 million, respectively (Alberta Energy 1998), while revenue from timber royalties and fees were approximately $100 million (Alberta Environmental Protection 1999). Revenues from product sales far exceeds these amounts, most of which is derived from exports. A significant proportion of the population is employed either directly or indirectly by energy and forestry. Continued economic growth in both sectors is anticipated.

A mechanism to monitor biodiversity in the forested portion of Alberta would enhance the economic and social climate that supports the province's energy and forestry sectors. Much of the activity in the energy sector, and all of the forestry activity, occurs on public lands, on which an array of regulations, policies, and legislation (Lee and Hanus 1998) are designed to foster economic activity while protecting ecological values, including biodiversity.

Despite numerous programs for monitoring various elements of biodiversity, Alberta's capacity to assess the success of these regulations and policies against biodiversity-related goals is limited (see Appendices 1, 2). For example, Lee and Hanus (1998) reviewed the legislation, policies, external agreements and programs related to the monitoring of biodiversity in Alberta’s forests, and over 100 monitoring programs, managed by over 30 government and non-government agencies, involving thousands of Albertans, were identified. Certain taxa, notably endangered species and harvested trees species, big game, and fish, have been the focus of past monitoring efforts. Clearly, these groups represent only a small fraction of Alberta's biodiversity, and for the vast majority of plant and animal species there are few records of long-term trends, and changes that may be associated with resource management activities are largely unknown.

Two reasons help explain this situation: (1) the priorities of resource management agencies with a monitoring capability and mandate are frequently driven by the need for information on the current status of a small number of species; (2) ecosystems are dynamic and biodiversity changes constantly without human intervention, making it difficult to distinguish natural changes from those caused by human activities (Swanson et al. 1993);

The large scale of resource management activities, combined with uncertainty over their effects on biodiversity, and a finite pool of resources, support the need for a more comprehensive approach to monitoring biological diversity. This need has been identified in a range of jurisdictions across North America (Bricker and Ruggiero 1998, Dixon et al. 1998, Langner and Flather 1994; Magnussen and Bonner 1997).

Support existing commitments to conserve biodiversity

Within the last decade, there have been numerous international, national, and provincial commitments to conserve biodiversity (Alberta Environmental Protection 1998c, Lee and Hanus 1998). These include the Canadian Biodiversity Strategy (Minister of Supply and Services Canada 1995) and Canada's Forest Accord (Canadian Council of Forest Ministers 1992), both of which have been endorsed by the Government of Alberta. The Canadian Biodiversity Strategy states: "Monitoring programs are required to detect and measure changes in biodiversity, to better understand functional linkages in ecosystems, and to evaluate the success or failure of biodiversity conservation and sustainable use policies and programs" (Minister of Supply and Services Canada 1995). Within Alberta, concern for the sustainable use of forest resources led to the creation of expert panels (Dancik et al. 1990, Alberta Forest Management Science Council 1997), and the Alberta Forest Legacy document (Alberta Environmental Protection 1998b). Each of these provincial initiatives included recommendations that Alberta's capacity to monitor forest ecosystems be improved.

National Parks obviously have a strong conservation mandate (Minister of Supply and Services Canada 1994, Woodley 1993), and the development of monitoring systems that area compatible with those on adjacent provincial lands would also assist in meeting requirements for reporting ecological integrity.

Support criteria and indicators processes

Federal and provincial governments are collaborating on a Canadian approach to Criteria and Indicators of sustainable forest management (Canadian Council of Forest Ministers 1995, 1996). Six criteria have been identified: (1) Conservation of biological diversity; (2) Maintenance and enhancement of forest ecosystem condition and productivity; (3) Conservation of soil and water resources; (4) Forest ecosystem contributions to global ecological cycles; (5) Multiple benefits of forests to society; and (6) Accepting society's responsibility for sustainable development. A total of 83 indicators have been identified, but quantitative data are lacking for many, including some related to biodiversity (Canadian Council of Forest Ministers 1996).

While the motivation for national level indicators is driven primarily by international pressure to demonstrate progress towards sustainable forest management, local initiatives have also been modeled on the Canadian Council of Forest Ministers approach. For example, the Foothills Model Forest in western Alberta has developed a draft list of indicators of sustainable forest management (Dempster 1998), which includes several related to biodiversity. A coordinated monitoring program would make it possible to document trends in these indicators both within and outside jurisdictions such as the Foothills Model Forest. This would facilitate assessments of whether changes within a single jurisdiction are local or regional in nature. Establishing a capacity to make regional comparisons is particularly important because target levels, or management "thresholds", are lacking in most local and national indicator processes.

Companies in the forest sector may seek certification of their management system through programs initiated by the Canadian Standards Association (1996) and the Forest Stewardship Council (cf. Appendix 3 of Elliott and Hackman, 1996).

Summary of strategic benefits

As outlined above, the potential contribution of environmental monitoring towards improved management of natural resources is considerable (Cairns 1996, Committee on Environment and Natural Resources 1997, Mulder and Palmer 1999). A summary of strategic benefits for Alberta is given in Table 1.1.

What kind of environmental monitoring do we need?

Although terminology varies, three forms of environmental monitoring can be recognized: implementation monitoring, validation monitoring and effectiveness monitoring (Hellawell 1991, Noss and Cooperider 1994, Mulder et al. 1999). While the Alberta Forest Biodiversity Monitoring Program is intended to be an effectiveness monitoring program, it is helpful to briefly distinguish it from the other two forms.

Implementation monitoring (Mulder et al. 1999) or compliance monitoring (Spellerberg 1991) is intended to determine whether planned activities are accomplished in the context of guidelines, standards, policies or legislation. Many references to monitoring in the Interim Forest

Management Planning Manual (Alberta Environmental Protection 1997) take the form of implementation monitoring.

Validation monitoring (Mulder et al. 1999) or monitoring to test one or more hypotheses (Spellerberg 1991) is most similar to traditional research, and can be used to investigate key management assumptions and relationships between management activities and observed effects (Mulder et al. 1999). This form of monitoring may represent the "research" component of a comprehensive monitoring framework (Committee on Environment and Natural Resources 1997). An effectiveness monitoring program would be enhanced considerably by supportive research directed towards key monitoring assumptions.

The third form of environmental monitoring, effectiveness monitoring or trend monitoring (Spellerberg 1991), documents the status and trends of selected environmental attributes in order to evaluate progress towards management objectives (Mulder et al. 1999). These objectives may be very broad (e.g., maintain assemblages of native species) or very specific (e.g., increase the number of spawning adults in a local fish population). The various forms of adaptive management (Walters and Holling 1990) all include some form of effectiveness monitoring to determine the outcome of management activities that are undertaken in support of a stated objective.

Effectiveness monitoring may be most meaningful if it provides insights into the causal relationships between management activities and ecosystem responses (Noon et al. 1999:27). Such an approach, accompanied by a conceptual model that links potential stressors with ecological responses, makes it possible to explain the causes of observed trends, and to predict future trends under alternative management scenarios. Unfortunately, limited knowledge of ecological relationships, especially in systems characterized by multiple stressors with unknown cumulative effects (e.g., Alberta), makes it difficult to construct a detailed conceptual model. This may result in the monitoring of elements that do not respond strongly to supposed stressors and, conversely, may result in the detection of trends arising from unanticipated causes. Under such circumstances (which may be the rule rather than the exception), the selection of elements to include in an effectiveness monitoring system should consider a range of criteria in addition to presumed relationships to stressors (see below).

It should be noted that effectiveness monitoring generally is intended to support the dual objectives of reporting both status and trends. Status refers to the level of a monitored element during one time, while trend refers to a change in the level of an element through time. "Early decisions on policy often are based on status estimates, with concerns about trends emerging later as decision makers seek evidence of the effectiveness of their decisions. Thus, choice of monitoring design must reflect and balance both status and trend estimation" (Urquhart 1998:256).

What makes a successful environmental monitoring program?

If the success of an environmental monitoring program is judged against its contribution to informed management decisions, or its value in preventing ecological crises, then "few examples exist of successful monitoring programs at the ecosystem scale" (Noon et al. 1999:25, see also Dickson et al. 1998). Noon et al. (1999) suggested several reasons why many monitoring programs fail: "minimal foundation in ecological theory or knowledge; little logic to support selection of indicators; no necessary understanding of causation; trigger points not identified; and no connection to decisionmaking”.

Arguably the most ambitious response to this lack of successful ecological monitoring programs in North America is the establishment of the Environmental Monitoring and Assessment Program (EMAP) by the US Environmental Protection Agency following a recommendation by EPA's Science Advisory Board in 1986 (Draggan 1995). The initial goals of EMAP were to: 1) Estimate the current status, trends, and changes in selected indicators of condition of the nation's ecological resources on a regional basis with known confidence; 2) Estimate the geographic coverage and extent of the nation's ecological resources with known confidence; 3) Seek associations between selected indicators of natural and human stresses and indicators of the condition of ecological resources; and 4) Provide annual statistical summaries and periodic assessments of the nation's ecological resources" (National Research Council 1995:2). Despite an investment of millions of dollars over several years, a recent evaluation conducted by the National Research Council (1995) concluded that EMAP is unlikely to meet these goals. The evaluation committee cited several concerns, including insufficient sampling intensity, insufficient rationale for the selection of indicators to measure change, lack of assessment endpoints, and organizational difficulties such as insufficient integration of information and lack of staffing continuity (National Research Council 1995). The evaluation committee also provided several recommendations regarding statistics, sampling and design, indicator selection, integration, choice of appropriate scale and boundaries of regions, coordination and management, external scientific review, and information management. While some of these recommendations are described in more detail below, readers are encouraged to consult the original text (National Research Council 1995) for further information.

Despite numerous suggestions of ways to enhance the ultimate success of a monitoring program (e.g., Spellerberg 1991, Noss and Cooperider 1994, Noon et al. 1999), differences in management regimes and institutional arrangements make it difficult to adopt a single set of suggestions that will fit all situations. Nonetheless, two sets of suggestions are particularly relevant to the development of a forest biodiversity monitoring program in Alberta.

First, Noss and Cooperider's (1994) guidelines for developing a monitoring program at the regional landscape level were as follows:

1. Clearly stated management goals and objectives (which frequently are comprised of two sets, one clearly outlined in regulations and legislation, the other represented by non-binding but potentially influential policy or position papers by stakeholder groups).
2. Construction of a well-defined but flexible plan using appropriate expertise.
3. Planned redundancy to prevent serious problems when parts of the program are unsuccessful.
4. Ensuring that monitoring is conducted at appropriate spatial and temporal scales.
5. Emphasis on the detection of trends towards a desired condition when the desired condition requires a long time to occur.
6. Clear distinction between implementation monitoring and validation monitoring (see above).
7. Careful selection of indicators.
8. Judicious use of science, statistics, and appropriate personnel.
9. Separation of monitoring from management at the same level of organization.
10. Fostering sustainability of monitoring by building an institutional structure whose sole responsibility is monitoring.
11. Ensuring that monitoring is issue-driven, that it detects changes in biodiversity, and that results can be incorporated into management.

In another set of suggestions, Noon et al (1999:28) suggested several requirements for a defensible effectiveness monitoring program, some or which are the same as those listed above:

1. Clearly stated management goals and objectives;
2. Clear statement of why the monitoring program has value;
3. Identification of factors that may make it difficult to meet management goals and objectives; these are best incorporated into a conceptual model of cause and effect;
4. Clear explanation of the rationale for selecting environmental attributes (indicators) to be measured;
5. An outline of sampling design and measurement methodology for each attribute;
6. Explanation of expected statistical precision and power to detect trends, which must be reasonable in the context of management goals; and
7. Procedures that connect monitoring to decision making (also recommended by Morrison and Marcot 1995).

Interested readers should also review the 24 "Recommendations for a National Environmental Monitoring Framework" of the Committee on Environment and Natural Resources (1997).

What to monitor?

Indicators and stressors

The term "indicator" is widely used to describe trends in economic conditions (Auerbach 1982, in Karr and Chu 1997), and indicators such as the number of unemployment claims and building permits are frequently combined into an index such as the "index of leading economic indicators" (Karr and Chu 1997:45). Environmental indicators are frequently used to describe ecological conditions in relation to a particular "standard, value, objective or goal" (Environmental Protection Agency 1972 in McRae et al. 1995). Noss (1990) defined indicators as "measurable surrogates for environmental end points that are assumed to be of value to the public". McKenney et al. (1994:4) suggested that indicators are simply "variables that we choose to monitor".

When considering indicators, a distinction is required between use of the term to describe factors that cause ecosystem change versus the ecological effects of such factors (e.g., Environmental Protection Agency 1972, Shackell et al. 1993, McKenney et al. 1994). For example, the

Environmental Protection Agency (1997) referred to "pressure indicators" when reviewing human activities that may stress ecosystems.

In this discussion, we follow the terminology of Noon et al. (1999) in separating "stressors" from "indicators". Stressors are "intrinsic and extrinsic drivers of change, either positive or negative... natural and human-induced disturbance events resulting in significant ecological effects", while an indicator is "any living or nonliving feature of the environment that can be measured or estimated and that provides insights to the state of the ecosystem" (Noon et al. 1999:121-122). Note that this use of the term indicator is not limited to single species (e.g., Landres et al. 1988) or guilds (e.g., Block et al. 1987, Kremen 1992), nor does it require that each indicator be a surrogate for other members of a larger group that are not monitored (e.g., Canadian Council of Forest Ministers 1995). Rather, indicators should be selected to create a suite of measures intended to convey useful information about status and trends within an ecosystem.

Stressors

Identifying stressors helps to focus the scope of a monitoring program based on probable cause-effect relationships (Noon et al. 1999, Roux et al. 1999). As noted above, stressors are "drivers of change" in an ecological system (McKenney et al. 1994:13; Noon et al. 1999). While the term frequently refers to undesirable effects (e.g., National Research Council 1995), this distinction is not necessary, particularly if disagreement exists regarding what constitutes an "undesirable effect". More important is the identification of factors that are believed to cause ecological change. Each stressor should be associated with one or more predicted ecological effects; these causal relationships can form the basis of a conceptual model to guide the selection of elements to monitor. Monitoring of stressors themselves, in addition to biotic elements, can guide interpretations of biodiversity change and assist in the refinement of conceptual models (Shackell et al. 1993).

A proposed list of stressors and their predicted effect on biodiversity in the forested portion of Alberta is given in Table 1.2. The stressors are divided into two broad categories based on the primary method that would be used for data collection, either remote sensing (at multiple scales) and field sampling (aquatic and / or terrestrial). Note that data collection refers to the monitoring of indicators believed to respond to each stressor, which are listed with the corresponding stressor. The association of one or more indicators with each stressor provides a crude conceptual model, and monitoring resource management activities associated with each stressor would provide explanatory variables that can lead to an improved understanding of the causes of biodiversity change.

Indicators of biodiversity

Defining biodiversity

The general concept of biodiversity has been in use for a long time but its widespread expression dates to several publications in 1980 (Harper and Hawksworth 1994). Norse et al. (1986) articulated the contemporary concept of biodiversity as referring to the three levels of organization; genetic, species, and ecological. Biodiversity is the contraction of "biological" and "diversity", and the term itself was coined in 1985 and sanctified in the proceedings of the 1986 ‘National Forum on BioDiversity’ published under the title *Biodiversity* (Wilson 1988). The first references to ‘biodiversity’ in *Biological Abstracts* appeared in 1988 (Harper and Hawksworth 1994).

The Canadian Council of Forest Ministers (1995) defined biodiversity as "the variability among living organisms and the ecological complexes (ecosystems) of which they are a part", and divided biodiversity into three broad elements: ecosystem diversity, species diversity, and genetic diversity. Other definitions of biodiversity are remarkably similar: Bunnell (1995) reviewed the major definitions and concluded that all refer to all levels of organization from genes to ecosystems, all address variability explicitly, while some refer to functional diversity.

Biodiversity is important because it provides the foundation for all the products, services, and other values we derive from forest ecosystems (Boyle 1991, Burton et al. 1992). This foundation includes basic ecosystem processes such as productivity and decomposition, stability and recovery from disturbances, and adaptability to changes in climate (Christensen et al. 1996). Conserving biodiversity at all scales is considered prudent given the uncertainty of future social and economic uses of biodiversity, and with respect to forests' ability to persist under changing climate and other global conditions (Minister of Supply and Services Canada 1995, Canadian Forest Service 1997).

Organizing biodiversity

Biodiversity is so inclusive that it is not measurable *per se* (Lautenschlager 1997). For example, biodiversity at the species level in Alberta involves over 60,000 species (Table 1.3), which does not include the infinitely large number of ecological processes and relationships between species and the structures they create at multiple scales. Therefore, in order to "monitor biodiversity", it is necessary to select a small number of biodiversity elements that comprise a useful suite of indicators. Noss (1990) proposed a hierarchical characterization of biodiversity reflecting multiple levels of biological organization, and suggested that biodiversity is observable at the regional landscape, community-ecosystem, population-species, and genetic levels of organization, and that inventory and monitoring tools are available to describe biodiversity at each level. Noss (1990) also recognized Franklin's (1981) three primary ecosystem attributes (composition, structure, and function), and suggested that each attribute applies at all four levels of organization.

This framework is useful for communicating the emphasis of a particular monitoring program (Salwasser 1993, Noon et al. 1999:34), given that it is difficult for any one program to apply effort evenly across all four levels of biological organization and all three ecosystem attributes.

Selecting biodiversity indicators

The quest for biodiversity indicators has consumed scientists and natural resource managers for over a decade (e.g., Noss 1990, Barber 1994, McKenney et al. 1994; Geomatics International Inc. 1999), and there is no sign of an emerging consensus on which attributes might be good indicators. Acknowledging the difficulty of this task, the National Research Council (1995:6) recommended that the Environmental Monitoring and Assessment Program "should initiate a major, focussed research program on indicator development". Much of the difficulty arises from a rudimentary understanding of ecosystem function, specifically the nature and magnitude of interactions of species with each other and with abiotic factors. This problem is not likely to be resolved soon (Noon et al 1999:29).

There is also no sign of an emerging consensus on the appropriate criteria to use when selecting environmental indicators to monitor. The following list is far from complete:

- can be accurately and precisely estimated; high signal-to-noise ratio (Lewis et al. 1995, Chojnacky 1995; Noon et al. 1999)
- can be monitored with low environmental impact (Lewis et al. 1995)
- capable of providing a continuous assessment over a wide range of stress (Noss 1990, Woodley 1993)
- easily and cheaply measured or counted (Noss 1990, Spellerberg 1991, Marshall et al. 1993, Lewis et al. 1995; Noon et al. 1999)
- easily understood by the public and by decision makers (Marshall et al. 1993)
- for a suite of indicators: accommodate a wide range of spatial and temporal scales, from individual to community to ecosystem (Noss 1990, Woodley 1993)
- low natural variability, or additive variation, and changes in their values can readily be distinguished from background variation (Noon et al. 1999:35)
- low variance within a single measurement period (Lewis et al. 1995)
- measurable over a broad geographic area (Noss 1990)
- reflect current understanding of ecosystem behaviour (Munn 1993)
- relatively independent of sample size (Noss 1990)
- relevant to identified issues of concern (Marshall et al. 1993)
- satisfies principal stakeholders and users (Munn 1993)
- sensitive to ecological variability and therefore able to provide early warning of change (e.g., Noss 1990, Marshall et al. 1993, Munn 1993, Woodley 1993; Noss and Cooperider 1994, Lewis et al. 1995; Noon et al. 1999);
- an indicator should serve as a surrogate for a larger environmental component or system of ultimate interest (Noss and Cooperider 1994; Noon et al. 1999:35).

Based on a selection of these recommendations and other considerations, we suggest that three criteria be applied to the process of selecting a suite of indicators to monitor in Alberta's forests:

1. Cost-effectiveness: Each indicator should be easy and inexpensive to monitor with high precision, so that a relatively small proportion of overall resources are required to obtain sufficient data at each monitoring location.

2. Relationship to stressors: Indicators should have a reasonably high probability of responding to predicted stressors, based on existing knowledge of ecological processes and relationships in Alberta's forests.

3. Multiple levels of biological organization: The suite of indicators should span multiple levels of biological organization with an emphasis on ecosystem structure and composition (Table 1.4), accompanied by recognition that for indicators that involve

species, it is difficult to rationalize the importance of one species or group of species over another except in the context of the above two criteria.

Based on these criteria, a preliminary list of biodiversity indicators for monitoring in Alberta's forests is given in Table 1.5. The list is guided by the preliminary recommendations provided elsewhere in this volume by Franklin and Dickson (in prep.), Lee and Hanus (in prep.), Scrimgeour and Kendall (in prep.), Shank and Farr (in prep), and Winchester (in prep.). Indicators are grouped by the primary method used for data collection, following the multi-resolution approach described by Franklin and Dickson (in prep.), and each indicator is associated with one or more stressors (Table 1.2). This arrangement provides a practical basis for organizing indicators while illustrating probable causes of change.

An integrated framework for monitoring forest biodiversity in Alberta

The need for an integrated framework

"Ecosystems span many levels of scale and complexity. A comprehensive forest ecosystem monitoring system will approach the problem from multiple perspectives and scales simultaneously" (Gillespie 1995:241).

As noted in the previous section, there are few examples of successful programs that monitor trends in biodiversity across large areas. Among the most frequently mentioned problems of existing programs is a lack of focus and unclear monitoring objectives (e.g., Noon et al. 1999). Part of the difficulty appears to stem from the temptation to design a single program that satisfies multiple goals, thereby ensuring that no single goal is met satisfactorily. Because of the enormous complexity of both ecological systems and natural resource management, it seems unlikely that a single approach would suffice (Gillespie 1995).

The notion of integrated monitoring designs is not new. The Committee on Environment and Natural Resources (1997) proposed a conceptual framework for achieving the multiple goals of environmental monitoring and research that consisted of three levels: (1) inventories and remote sensing programs over large areas; (2) national and regional resource surveys; and (3) intensive monitoring and intensive research sites. This framework would provide opportunities to integrate information obtained at each level with that obtained at other levels. For example, the collocation of regional monitoring sites (Level 2) with intensive monitoring sites (Level 3), would improve the ability to interpret observed trends, particularly if they were examined in the context of land use trends monitored via remote sensing (Level 1). Such an approach is consistent with Gillespie's (1995) recommendation that monitoring and research not be viewed separate activities, and that monitoring within a hierarchical framework is both efficient and effective.

An integrated design for monitoring forest biodiversity in Alberta is outlined in Table 1.6, and described in the following four sections. While distinct from that suggested by the Committee on Environment and Natural Resources (1997) for integrating national research and monitoring, this framework is similarly organized along a hierarchy of spatial scales. Four monitoring levels are suggested:

- Provincial Trend monitoring
- Regional Trend monitoring
- Large-scale Management Experiments
- Long-term Research Sites

Although no single level can be viewed as more "important" than another, the current emphasis of the Alberta Forest Biodiversity Monitoring Program is on Regional Trend monitoring.

Provincial Trend monitoring

Goal

The goal of Provincial Trend monitoring is to monitor the status and trends of selected elements of biodiversity in the four forested natural regions of Alberta (Rocky Mountains, Foothills, Boreal Forest, Canadian Shield), a total area of approximately 500,000 km^2. No attempt is made to resolve trends for smaller areas.

General design

Provincial Trend monitoring is conducted from a network of monitoring sites established in the forested natural regions of Alberta (Fig. 1.1). This monitoring level is characterized by low site density, high measurement frequency, and a large number of indicator variables monitored using both remote sensing and ground sampling (Table 1.6). Provincial Trend sites are similar in purpose and design to the "index sites" described by the Committee on Environment and Natural Resources (1997), and the "sentinel sites" of Jassby (1998).

Monitoring at this level would potentially be similar to the United Kingdom Environmental Change Network (Sykes and Lane 1996, Schneider 1997) which consists of 11 terrestrial and 42 freshwater sites throughout the United Kingdom.

Significance

Provincial Trend monitoring is intended primarily to contribute to government reporting mandates related to the status and trends of forest biodiversity, but would also support Regional Trend monitoring. By monitoring the same "core" set of variables in both Provincial and Regional trend sites, along with additional variables in Provincial Trend sites, it would be possible to better understand the relationships among a larger set of monitored variables. This improved understanding could be used to refine indicators, facilitate the development of new indicators, contribute to models of ecosystem dynamics, and establish patterns of temporal variability (Shackell et al. 1993, Committee on Environment and Natural Resources 1997).

Linkages

Linkages are possible with national monitoring programs currently being developed, including the National Forest Inventory (Lowe et al. 1991, Magnussen and Bonner 1997), Criteria and Indicators of Sustainable Forest Management (Canadian Council of Forest Ministers 1996), and the Ecological Monitoring and Assessment Network (EMAN) of Environment Canada (Brydges 1995). (There are currently three EMAN sites in the forested regions of Alberta: the Meanook Biological Research Station, the Terrestrial and Riparian Organisms, Lakes and Streams (TROLS) study area, and the South Waterton Biosphere Reserve.)

Regional Trend monitoring

Goal

The goal of Regional Trend monitoring is to monitor status and trends for selected elements of biodiversity within defined regions in the forested portion of Alberta. A completely systematic or random arrangement of sampling sites is intended to facilitate trend reporting within a range of region classes based ecological or administrative criteria (Fig. 1.1).

General design

Regional Trend monitoring would be conducted from a network of monitoring sites that are established at a much higher density than in the Provincial Trend monitoring network (Fig. 1.1). Effort per site and measurement frequency are low, with a small number of indicators monitored using both remote sensing and ground sampling (Table 1.6). Design-based inference (as distinct from model-based inference) is intended to permit extrapolations from sites to the larger regions in which they occur (Urquhart et al. 1998). Within each region, a simple random or systematic sampling design would permit extrapolation to the entire monitored area (Cochran 1977, Krebs 1989). Such generalizations are not possible if only "representative" or "arbitrary" locations are monitored. It may also be possible to correlate observed trends in biodiversity with trends in land use that are also measured at each monitoring site, facilitating subsequent research into the causes of biodiversity change (Gillespie 1995).

Establishing a Regional Trend monitoring system would be relatively straightforward if regions were identified *a priori*. However, there are benefits associated with defining regions based on a range of different ecological and administrative criteria, and it is proposed that sampling sites be located in a completely systematic or random fashion across the forested portion of Alberta. This would permit alternative definitions of "regions" for the purpose of trend reporting.

Ecologically defined regions (Fig. 1.2) that may be appropriate for reporting trends include natural subregions (Alberta Environmental Protection 1994), ecodistricts (Alberta Environmental Protection 1994), and watersheds (Thorsteinson and Taylor 1997). Defining regions on criteria such as these may confer statistical benefits by controlling for environmental heterogeneity and improving the ability to detect trends for certain indicators (National Research Council 1995, Omernik and Bailey 1997). In addition, ecological regions defined on the basis of climate, weather, topography, and glacial history are relatively permanent in the context of a monitoring program lasting several decades (Rowe 1999).

Ecological boundaries may not correspond well with administrative jurisdictions for which trend detection has immediate strategic value, and defining regions using administrative boundaries (Fig. 1.2) will be necessary. Examples include Forest Management Agreement areas, petroleum leases, National Parks, other protected areas, and provincial government jurisdictions such as

Forest Management Units and Wildlife Management Units. Most administrative jurisdictions do not occur across the entire forested portion of Alberta.

The most appropriate basis for defining regions for trend monitoring may be ecodistricts, which are delineated based on broad physiographic features and landforms, and are mapped over the entire land area of Alberta (Fig. 1.2). The ecological patterns reflected by ecodistricts may provide an appropriate basis for summarizing ecological trends (Omernik and Bailey 1997). Of the approximately 150 ecodistricts in Alberta, approximately half are between 2,500 km^2 and 10,000 km^2 in size, with most of the remainder smaller than 2,500 km^2 (Fig. 1.3). In comparison, most Forest Management Agreement (FMA) areas are also between 2,500 km^2 and 10,000 km^2 in size (Fig. 1.3). Although there is little correspondence between the boundaries of these two potential classes of regions, establishing a uniform density of Regional Monitoring sites across the entire forested portion of Alberta that is appropriate for monitoring trends within most ecodistricts would also permit trends to be reported within most FMA areas. Very small ecodistricts and FMA areas that are adjacent to one another could potentially be grouped for monitoring purposes. The largest protected areas (National Parks, Figs 1.2, 1.3) are larger than most ecodistricts, and this system would permit National Parks to monitor trends by ecodistrict.

The most significant logistical (financial) challenge for Regional Trend monitoring is to achieve a site density that is capable of resolving trends at spatial scales that are ecologically relevant and applicable to the scale of natural resource management (Schneider 1997).

Regional Trend monitoring would be most similar to existing provincial forest monitoring programs (e.g., Alberta Environmental Protection 1997b, Foret Quebec 1998) and the U.S. Forest Inventory and Analysis program (U.S. Department of Agriculture 1993, Gillespie 1995). These programs monitor forest vegetation using a Continuous Forest Inventory approach (Stott 1947, Scott 1998) consisting of a randomly located permanent sample plots. Similarities are also possible with Ontario's Wildlife Assessment Program (McLaren et al. 1998), which aims to monitor populations of representative forest vertebrates at an ecoregion level. Regional aquatic monitoring programs are in place within numerous U.S. states (Davis et al. 1996).

Significance

Regional Trend monitoring provides the "feedback" required for successful natural resource management (Committee on Environment and Natural Resources 1997, Dixon et al. 1988, Urquhart et al. 1998, Noon et al. 1999). Provided the density of sampling sites and other design variables are adequate for resolving trends at an appropriate scale, monitoring at this level would contribute to the reporting mandates of individual management organizations such as National Parks, Lands and Forest Service, Natural Resources Service, and companies in the forestry and energy sectors.

Large-scale Management Experiments

The value of large-scale management experiments for managing natural resources was clearly articulated by Walters and Holling (1990). While there are some notable examples of ecological field experiments operating at smaller scales, such as Ecosystem Management Emulating Natural Disturbance (Volney et al. 1999) and Montane Alternative Silvicultural Systems (Arnott and Beese 1997), there are few examples of large-scale experiments in forest resource management (Walters 1997).

If natural resource management in Alberta is viewed as an "experiment", then Regional Trend monitoring may provide one mechanism for monitoring relevant responses in the context of "passive adaptive management" (Walters 1986). Data from Regional Trend monitoring may provide opportunities to examine the response of biodiversity to natural resource management through comparisons among regions with different management histories. For example, regions with little or no industrial development (e.g., protected areas) could be compared to regions with a long history of intensive management. In addition, it may be possible to modify the Regional Trend network to facilitate comparisons that would otherwise not be possible. For example, because there are few large protected areas in Alberta (Figs. 1.2, 1.3), few would contain a sufficient number of sites to permit the reporting of trends if site density was uniform across the province. This could be improved by increasing the number of Regional Trend sites within a selection of protected areas.

However, despite the potential for "tinkering" with a Regional Trend monitoring network, the statistical properties of regions and monitoring sites will likely not provide optimal experimental designs for answering many important questions. In particular, they may not possess all the key features of reliable management experiments listed by Walters (1992):

1. contrasting management treatments for comparison of performance;
2. replication to insure that apparent treatment differences are not accidents due to study site effects;
3. interspersion of experimental units over large regions, to insure that measured differences are broadly applicable; and
4. carefully selected set of response measurements (rather than the false pretence that "all relevant factors will be measured").

Walters (1992) added: "the hallmarks for future management experiments should be more sites, bigger sites, and innovative monitoring technologies... if using more experimental areas means measuring much less on each area, then what we should be concentrating on is how to priorize the most important measurements and how to do innovative monitoring more cheaply...."

Certain aspects of Regional Trend monitoring as described previously are consistent with these recommendations in having a small number of variables monitored at a large number of sites using a combination of remote sensing and field sampling methods. The missing element is an appropriate experimental design, which requires careful consideration to ensure reasonable statistical power (Nemec 1991). As illustrated in Fig. 1.1, sampling sites within a large-scale management experiment may be collocated with Regional Trend monitoring sites, thereby improving the efficiency of both monitoring levels.

Long-term Ecological Research Sites

Long-term ecological research sites represent a minor component of the integrated monitoring framework presented here, and are not included in Fig. 1.1. However, they could play a research role in support of Regional Trend monitoring (Committee on Environment and Natural Resources 1997). Such sites are generally established in the context of specific research, education, demonstration, or other objectives. All have the common feature of consistent, repeated monitoring of ecological variables over time. Examples include the U.S. Long Term Ecological Research Network (Franklin et al. 1990).

Cost-effectiveness of regional trend monitoring designs

During the planning of Regional Trend monitoring, resources must be allocated in a way that maximizes the probability of accomplishing the objectives. Because much of Alberta is distant from easy ground access, travel cost is expected to represent a significant portion of the overall budget. The expense of monitoring a large number of sites may partly explain why systems for monitoring regional status and trends are scarce (Committee on Environment and Natural Resources 1997, Noon et al. 1999, Dixon et al. 1988).

The effectiveness of alternative design scenarios may be evaluated in relation to three variables: number of sites, sampling frequency, and sampling effort at each site. These three design variables "compete" with one another for resources allocated to monitoring (Millard and Lettenmaier 1986, Urquhart et al. 1998).

A cost-effectiveness model (Stelfox 1999, Appendix 4) can be used to estimate the cost of each design in relation to its effectiveness, with each scenario representing different combinations of levels for each design variable. For example, one design might include 500 sites sampled once every 3 years, with 2 days of field effort allocated to each site, while another design might include 2000 sites sampled every 5 years, with 1 day of effort per site. The optimal design is expected to be one that contains a large number of sites, in which the sampling effort directed towards each site is small relative to the total monitoring effort (Millard and Lettenmaier 1986).

Power analysis is the appropriate tool for evaluating the effectiveness of such alternative monitoring designs (Green 1989, Zeilinski and Stauffer 1996, Resource Inventory Branch 1998, Urquhart et al.1998, Noon et al. 1999). For analyses of trends through time, power is the probability of detecting a trend should it occur (Gerodette 1987), while the power of a regional status comparison is the probability of detecting a differences between regions, should one exist (Cohen 1988). In general, power increases with increasing sample size, trend magnitude, and significance level, and declines with increasing sample variance (Thomas and Krebs 1997). If too few sites are monitored too infrequently, achieving reasonable power will be impossible, but once reasonable power is achieved, sampling additional sites is an inefficient use of resources.

Statistical power objectives must be stated explicitly (Millard and Lettenmaier 1986), and the following preliminary power objectives are proposed for the Alberta Forest Biodiversity Monitoring Program:

- The minimum level of statistical power for regional status comparisons is to be able to detect a minimum difference between regions with at least 90% certainty ($\beta = 0.1$) and less than 20% probability of being incorrect ($\alpha = 0.2$). The simplest case is for the comparison of two regions; the minimum detectable difference (effect size) is set at 10% above and below of the mean of both regions combined.
- The minimum level of statistical power for trend analysis is to be able to detect a 30% change 10 years, equivalent to a 3% annual change (Urquhart et al. 1998:255). The trend is to be detected with at least 90% certainty ($\beta = 0.1$) and less than 20% probability of being incorrect ($\alpha = 0.2$).

Any power analysis requires that that something be known or estimated about the population of elements to be monitored. For trend analysis, two parameters are necessary: the variability within sites, and the initial levels of each monitored element (Gerodette 1987, Chojnacky 1995). (Temporal variability is considered a component of within-site variability (Nur et al. 1995, Gibbs et al. 1998)). For regional status comparisons, one parameter is necessary: the variability among sites within each region (Nemec 1991).

Within-site variability represents the combined effects of 1) small-scale temporal and spatial variation in the element of interest; and 2) the variation associated with observers and measurement techniques (Link et al. 1994, Millard and Lettenmaier 1986, Gibbs et al. 1998). Eberhardt and Thomas (1991) noted that "environmental research techniques are subject to substantial measurement errors". This source of variability has also been referred to as "index variance" (Urquhart et al. 1998:249) and "count variance" (Barker and Sauer 1995:125).

Where possible, minimizing within-site variability is advisable in a monitoring program designed to detect trends (Link et al. 1994), because this variability represents the "noise" that may obscure the "signal" of real trends in monitored elements (Eagle et al. 1998, Stow et al. 1998). Within-site variability of count data can be reduced by obtaining multiple counts within a single year (Link et al. 1994), although doing so not only requires resources that could otherwise be allocated to additional sites, but may also be of limited statistical value. Because of the high diversity of physical and biotic conditions across the forested portion of Alberta, variability among sites will likely be high for most monitored elements. Under such circumstances, obtaining multiple samples per year may not substantially increase the power to detect trends (Link et al. 1994). Gibbs et al. (1998) provided estimates of within-site variability based on published studies of population size for a range of plant and animal species.

For comparisons among regions, high variability among sites can limit the power of comparisons of the status of a monitored element. Among-site variability can be reduced by increasing the area sampled at each site (Bormann 1953, Scott 1998:231) by either increasing the area of sample plots (or transects), or increasing the number of plots within a site. Freese (1967) presented a simple method for quantifying the efficiency of two quadrat sizes for estimating population parameters. For time-constrained sampling methods such as point counts (Ralph et al. 1995) and pitfall traps (Spence and Niemela 1994), variation among sites can also be reduced by extending the duration of sampling at each site.

Implementation

Implementing even one level of the preceding integrated monitoring framework is a complex undertaking, and it would be highly beneficial to establish monitoring systems at all four levels. Palmer and Mulder (1999) recommended a structured approach to the implementation of effectiveness monitoring that included data collection, data summary, (including validation, analysis and report preparation), data interpretation, and decisionmaking, all linked by a coordination and support system. In the context of the Alberta Forest Biodiversity Monitoring Program, decisionmaking is not currently a formal part of the monitoring process; this may be a problem (Noon et al. 1999).

Stolte and Lund (1995) suggested several ways to maintain support for an environmental monitoring program (not all of which may be relevant to the Alberta Forest Biodiversity Monitoring Program):

- ensuring that it addresses broadly accepted concerns (such as biodiversity conservation);
- attempting to have the program required by law in order to survive changes in agency and government administrations;
- developing credible and persistent mentors at upper echelons;

- building partnerships at home and abroad;
- communicating results early, frequently, simply, and through a variety of media;
- acknowledging the support of partnerships; and
- continuous improvement.

The Internet is an appropriate venue for reporting the results of this type of monitoring program (Schneider 1997). At the national level, numerous templates are available, such as the Canadian Environmental Indicator Series (http://199.212.18.79/~ind/English/Home/default.htm), the Compendium of Canadian Forestry Statistics (http://nrcan.gc.ca/cfs/proj/iepb/nfdp/cp95/compen_e.htm), and the US National Environmental Monitoring Initiative (http://www.epa.gov/cludygxb/sites.html). Similar reporting mechanisms at the provincial or local scale are scarce; links with these national initiatives would be cost-efficient.

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Table 1.1 Summary of the benefits of effectiveness monitoring of forest biodiversity in Alberta.

Economic

Improved security of market access for participant companies and reduced probability of consumer avoidance based on concerns over biodiversity conservation. Participation in this monitoring program would also assist companies seeking product certification based on a demonstrated commitment to the principles of adaptive management, which requires that the company acquire information on the status and trends of ecological systems being managed.

Enhanced public confidence in Alberta's natural resource management capability would contribute to the maintenance of employment and economic activity within the natural resource sector.

Reduced duplication of research and administration costs by providing the opportunity for a "one-window" approach to monitoring that would be more economical and efficient than current approaches. Government and industry could share the cost of implementation.

Social

Reduced potential for conflicts among stakeholders over resource management issues, and reduced costs associated with such conflicts, by providing transparent, equal access to scientifically rigorous data on status and trends of forest biodiversity.

Increased confidence among Albertans that their natural resources are being managed in a sustainable fashion, which would potentially act to curb public support for a rigid regulatory framework.

Environmental and Scientific

Improved capability for adaptive management of natural resources by providing feedback on the status and trends of forest biodiversity in relation to resource utilization and management actions.

Improved ability to compare trends in biodiversity across meaningful spatial and temporal scales

Generation of a long-term data set available for review and analysis by scientists with expertise in forest ecosystems and biological diversity.

Application of common monitoring methods across multiple jurisdictions having different land use and natural disturbance histories would provide natural resource managers with a broader context against which to interpret changes within a single jurisdiction.

Development and enhancement of Alberta's capability for using remote sensing technology, such as Landsat, to periodically analyze and report on the pattern and composition of Alberta's forested landscapes.

Table 1.2 List of major stressors predicted to affect biodiversity in Alberta's forests, listed by the primary method used for data collection. Indicator numbers correspond to those given in Table 1.5.

Indicator(s)	Stressor
	Remote sensing (multiple scales)
1 2 3 4	**1** Changes in landscape composition and pattern by vegetation removal and linear developments
6	**2** Changes in watercourse morphometry by vegetation removal and linear developments
2 4 5	**3** Reduction in the area of selected vegetation types (e.g., old forests, fire-origin forests)
1 4	**4** Changes in broad vegetation patterns by modification of disturbance regimes
	Field sampling (aquatic and / or terrestrial)
7 8 10 11 12 13 14 15 16 17	**5** Changes in the composition, structure and function of biotic assemblages by removal of soil and vegetation followed by the establishment of vegetation dominated by trees or other plant taxa
7 8 10 11 12 13 14 16 18	**6** Changes in the composition, structure and function of biotic assemblages by removal of wood biomass followed by establishment and maintenance of vegetation dominated by trees
15 16	**7** Changes in the composition, structure, and function of biotic assemblages by the establishment of exotic or weed species and pathogens
7 8 10 11 12 15 16 17 18	**8** Changes in the composition, structure and function of biotic assemblages by modification of natural disturbance processes
10 11	**9** Changes in the physical and chemical properties of water by anthropogenic disturbance
15 17 20	**10** Changes in the physical and chemical properties of soil by anthropogenic disturbance
9	**11** Decline in the condition or health of selected tree species through deposition of airborne and waterborne pollutants
19	**12** Changes in the genetic composition of tree and other species through modification of disturbance regimes and linear developments

Table 1.3 Estimated number of species believed to occur in Alberta, by major taxonomic group. Further details are contained in Appendix 3. Source: AT. Finnamore, Provincial Museum of Alberta.

Plant Division, Animal Phylum	Estimated no. species
1. Fungi	12,000
2. Algae	18,000
3. Lichenes	unknown
4. Hepatophyta	162
5. Bryophyta	430
6. Pteridophyta	65
7. Coniferophyta	23
8. Magnoliophyta	1,115
9. Protozoa	9,600
10. Porifera	10
11. Cnidaria	5
12. Platyhelminthes	850
13. Gastrotricha	20
14. Rotifera	400
15. Nematoda	800
16. Nematophora	5
17. Acanthocephala	30
18. Bryozoa	5
19. Mollusca	80
20. Annelida	83
21. Arthropoda	17,700
22. Chordata	382
TOTAL	**61,765**

Table 1.4 A hierarchical framework for organizing biodiversity that reflects multiple levels of biological organization (after Noss 1990). Entries in each cell (high, moderate, low, none) indicate the current emphasis of the Alberta Forest Biodiversity Monitoring Program.

	Emphasis in the Alberta Forest Biodiversity Monitoring Program		
	Composition	**Structure**	**Function**
Regional Landscape	high	high	moderate
Community-Ecosystem	high	high	moderate
Population-Species	moderate	low	none
Genetic	none	none	none

Table 1.5 Candidate indicators of biodiversity to monitor in the forested portion of Alberta, by the primary method used for data collection. Stressor numbers correspond to those given in Table 1.2.

Stressor(s)	Indicators, grouped by the primary method used for data collection.
	Remote sensing (small scale, large area covered, patch >5 ha)
1 4	**1** Area and pattern of land cover classes (non-vegetated, vegetated), vegetation types (forested, reclaimed, agricultural), and forest types (coniferous, deciduous, mixedwood)
1 3	**2** Area and pattern of lands disturbed by forest harvesting, energy exploration and development, linear developments, and natural disturbances
1	**3** Photosynthetic capacity of vegetation
	Remote sensing (medium scale, patch approximately 0.5 ha)
1 3 4	**4** Area and pattern of vegetation patches defined by dominant species, age class, crown closure, and roughness
1 3	**5** Area and pattern of lands disturbed by forest harvesting, energy exploration and development, linear developments, and natural disturbances
2	**6** Watercourse morphometry
	Remote sensing (large scale, small area covered, patch <0.001 ha)
5 6 8	**7** Density of selected tree species (canopy cover, number of stems)
5 6 8	**8** Height, roughness, and transparency of tree canopy
11	**9** Condition and health of selected tree species
	Field sampling (aquatic)
5 6 8 9	**10** Benthic algae: number of species, total abundance, biomass
5 6 8 9	**11** Benthic macroinvertebrates: number of species, by taxon & functional group
5 6 8	**12** Fish: frequency of occurrence of selected species
5 6	**13** Amphibians: frequency of occurrence of selected species
	Field sampling (terrestrial)
6	**14** Trees: size distribution of living and dead individuals, by species
5 7 8 10	**15** Vascular plants (non-tree): number of species, by stratum and growth habit
5 6 7 8 10	**16** Arthropods: number of species, by taxon and functional group
5 6 8	**17** Birds: number of species, by taxon and functional group
5 6 8	**18** Mammals: frequency of occurrence of selected taxa
12	**19** Genetic composition of selected tree species
10	**20** Carbon content of soil

Table 1.6 An integrated framework for monitoring forest biodiversity in Alberta. The current emphasis of the Alberta Forest Biodiversity Monitoring Program is on Regional Trend nonitoring.

	Monitoring Level			
	Provincial Trend	**Regional Trend**	**Large-scale Management Experiments**	**Long-term Research Sites**
Number of sites in Alberta	few (< 100)	many (> 1,000)	many	n/a
Measurement frequency	high (annual)	low (2-10 yr)	low (1-10 yr)	variable, but high (annual?)
Effort per site	high	low	low	high
Number of indicators	many	few	few	many, but variable
Spatial resolution	coarse (500,000 km^2)	moderate (1,000 - 10,000 km^2)	variable	fine
Area sampled at each site*	large (100-1000 ha)	small (0.01 - 10 ha)	small (0.01 - 10 ha)	variable
Primary sampling methods	Remote sensing Field sampling	Remote sensing Field sampling	Remote sensing Field sampling	Field sampling

* sampled area may vary among indicators

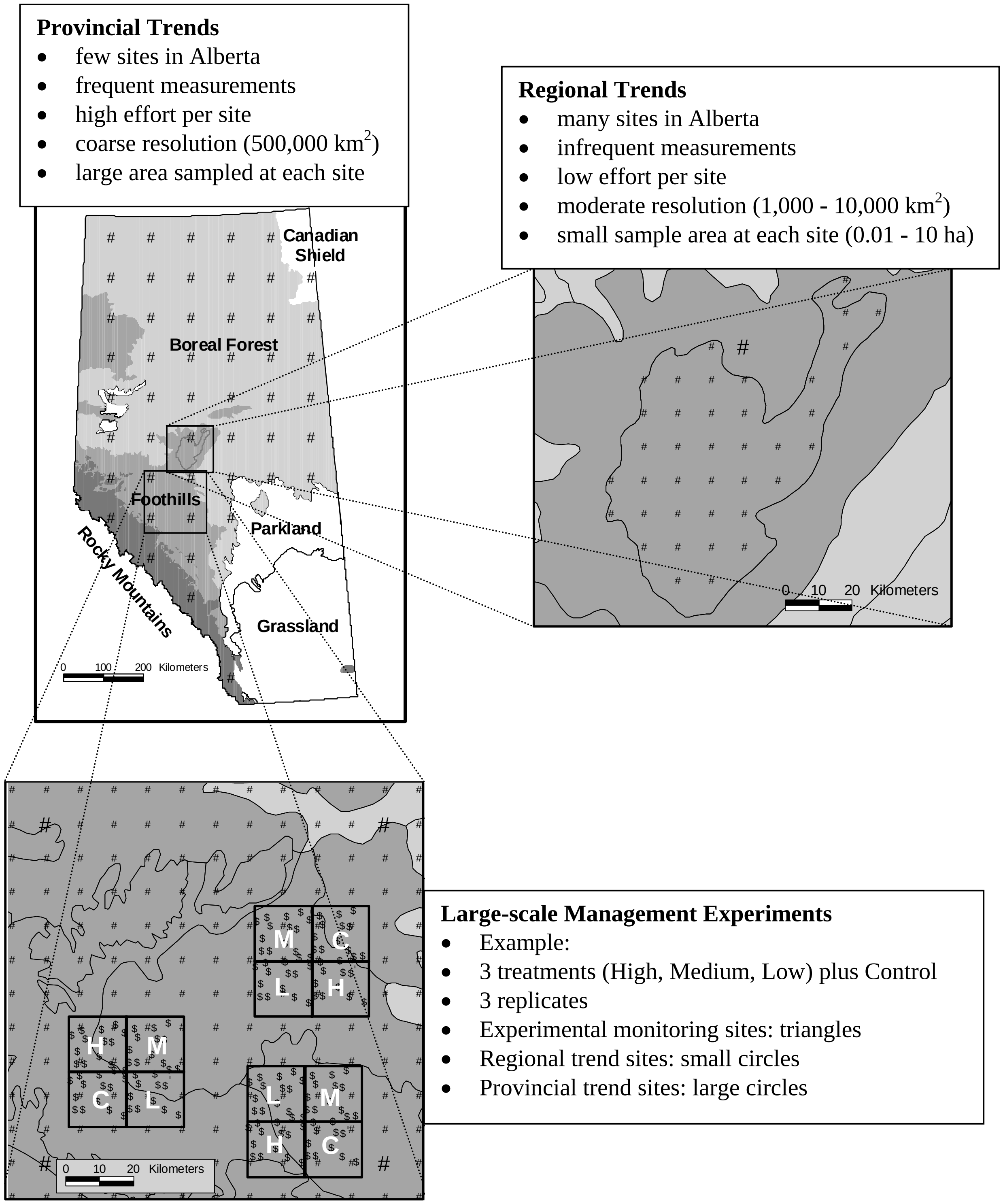

Figure 1.1 An integrated framework for monitoring forest biodiversity in Alberta. All site densities are hypothetical; designs are pending further cost-effectiveness analyses. In the Regional Trends example, trends are monitored within ecodistricts, and a single ecodistrict (Swan Hills; 3,735 km^2) is shown; other definitions of regions are possible (e.g., natural subregions, watersheds, Forest Management Agreement areas, petroleum leases, protected areas). In the Large-scale Management Experiment example, a hypothetical study design is shown to illustrate possible sample site locations in relation to Provincial and Regional trend monitoring sites.

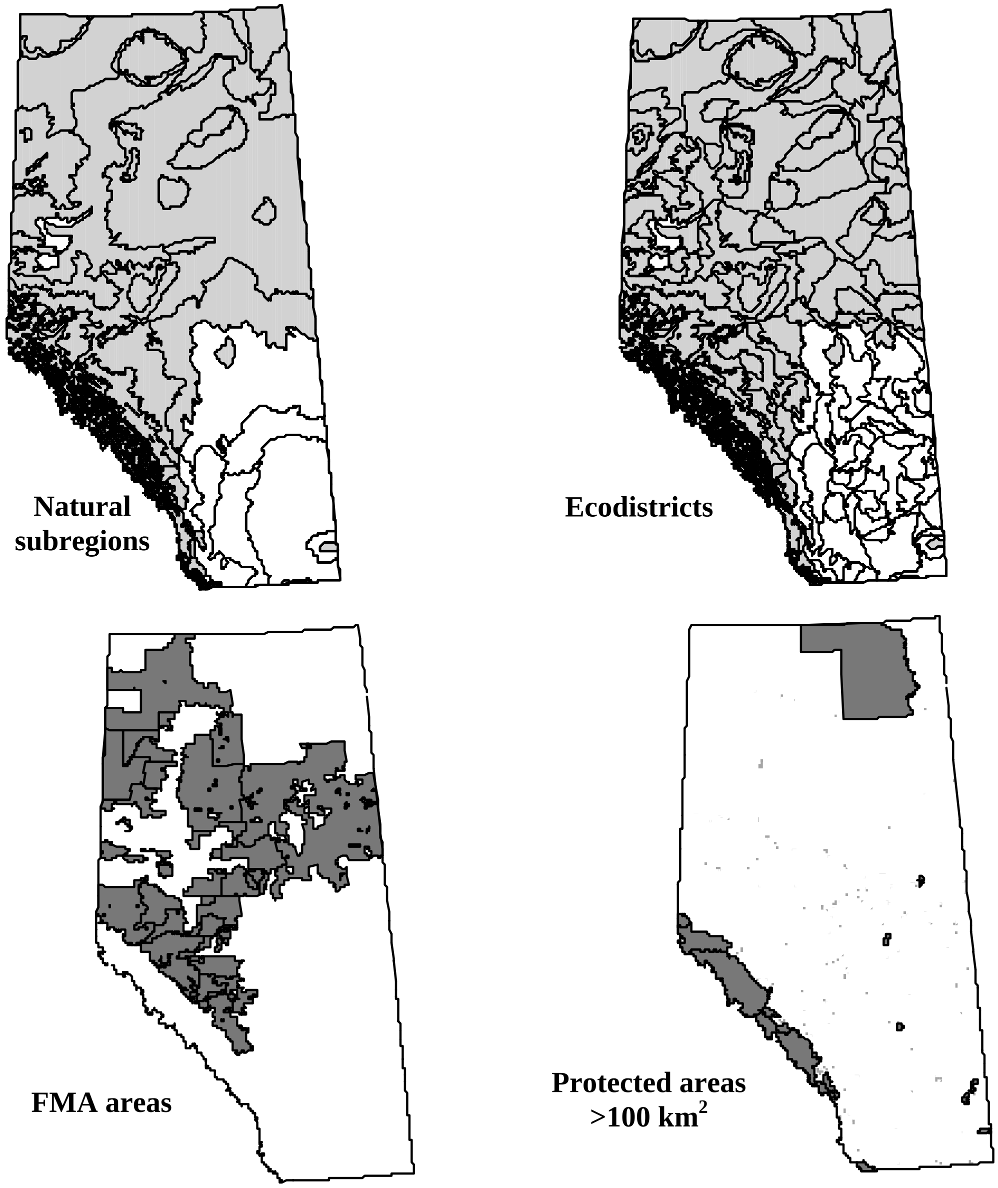

Figure 1.2 Map showing four potential classes of regions considered for Regional Trend monitoring. Natural subregions and ecodistricts that are dominated by forest cover are shaded. Note that only protected areas > 100 km^2 are outlined and darkly shaded; an additional 63 protected areas are between 10 and 100 km^2, and an additional 358 protected areas are between 1 and 10 km^2.

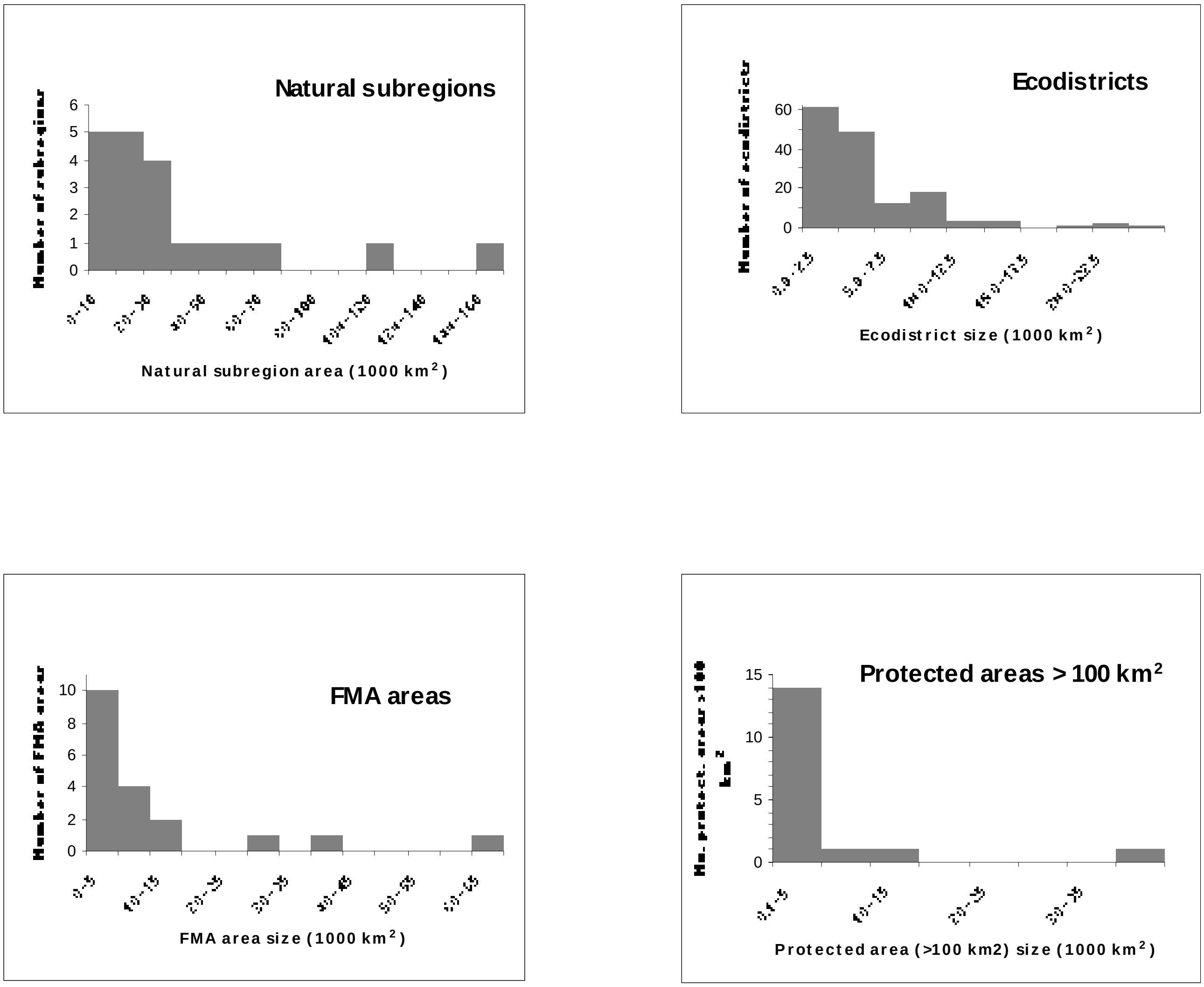

Figure 1.3 Size distributions within four potential classes of regions for which trends could be reported for Regional Trend monitoring. Note that only protected areas > 100 km^2 are included; an additional 63 protected areas are between 10 and 100 km^2, and 358 are between 1 and 10 km^2.