INDICATORS OF FOREST SUSTAINABILITY FOR ONTARIO BOREAL FORESTS: A FIRST APPROXIMATION

by

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ABSTRACT

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If humankind is to cope with the cumulative effects of its expanding populations on the earth's ecosystems, a new relationship is required with natural systems. Serious adoption of the concepts of forest sustainability and adaptive management of forest ecosystems has meant a shift from a commodity focus in forest management to a focus on maintenance of ecosystems. A key step within an adaptive management framework is to identify indicators of essential ecosystem features. Forest managers thus need to identify and apply indicators that can show whether forest sustainability is being achieved.

The working definition of forest sustainability developed and incorporated in this project is that a forest, to be sustainable, will retain its essential ecological composition, functions, and patterns, which support the full range of societal values, in both the present and the long-range future. Indicators were determined by developing measures for ecosystem features critical to ecosystem function and that satisfy a broad range of public values. Public involvement in this process included circulation of a preliminary suite of indicators, and a workshop to priorize indicators for development. Economic values were not directly considered in the study.

Indicator development and application are embedded in the principles of landscape ecology, necessary for the implementation of an ecosystem management philosophy. A first-approximation set of indicators designed for application to the managed boreal forests of Northern Ontario is presented, as well as a test application of the indicators to a boreal forest near Thunder Bay. Indicators identified and tested in relation to wilderness are remoteness, size of wilderness, and naturalness. Indicators presented in relation to biodiversity are: forest cover type diversity, forest age diversity, forest fragmentation, old growth forest and old growth interior forest fragmentation, forest edge length, and habitat supply for specific species - marten. Finally, road-related indicators identified and tested are road density, and forest conversion by roads and landings.

Recommendations for operational use of sustainability indicators in forest planning include the following. The public must be involved in the choice and formulation of indicators. Existing digital FRI databases, although problematic in some respects, can be an adequate starting point for indicator measurement. As a key component of managing for forest sustainability, indicator measurement will require additional personnel and effort.

Although indicator development and use will require more effort and money, development of at least a few indicaors for each forest management unit in Ontario should begin immediately. Indicator development is hampered by serious deficiencies in biophysical and socio-economic understanding of boreal forests. Indicators must be tested on a range of forecasts for the future structure of forests, under alternative management strategies. Since forest sustainability has become the first priority for forest managers, they will have to demonstrate to the public their success in the achievement of forest sustainability.

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CHAPTER 1: INTRODUCTION

Adaptive management is conceptually popular among foresters in Canada. This form of management (see: Holling 1978; Baskerville 1985, 1993; Walters 1986; Lee 1993; Ontario Forest Policy Panel 1993) acknowledges the great uncertainties inherent in managing large ecosystems for long periods into the future, and embodies processes that force learning to occur while management takes place. Management of the system itself becomes the subject of investigation, a vital source of knowledge for improving the care given to ecosystems while they are being used to meet people's needs and desires.

Adaptive management of natural resources and ecosystems is a hollow platitude unless: (a) explicit system-level objectives are set for all key values of the system being managed; (b) one or more quantitative indicators are defined for each objective; (c) explicit models are used to create forecasts of the expected future for each indicator in response to alternative action sets; (d) one of the analyzed action sets is chosen and implemented; (e) measurements are taken of action implementation, subsystem responses to individual actions, and whole-system responses to the whole action set; (f) measured data are compared with forecast data, differences noted, and reasons for the differences unearthed; and (g) new objectives and action sets are designed and implemented based on the new knowledge. Unfortunately, many who claim to espouse and practice adaptive management of forests are not following such basic protocols for active learning. If they are, they are keeping their progress a well-kept secret!

Enter "sustainable development". As a concept and basic truism, sustainable development has become popular with policy-makers and analysts in the resource management field, and indeed with most citizens in developed countries, in the late 1980s and early 1990s. The most widely heralded definition of sustainable development is "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED 1987). Perhaps sustainable development is an oxymoron - how can development (i.e., growth) be sustainable over the long term? To keep a strong emphasis on ecosystem health, the concept of forest sustainability, or ecosystem sustainability, is being promoted (Ontario Forest Policy Panel 1993; SAF Task Force on Forest Health and Productivity 1993). Forest sustainability requires that forests be kept in "good condition". This means that "good condition" must be defined, and forests must be managed in such a way that the good condition is maintained (Ontario Forest Policy Panel 1993).

Much attention has been given by Canadians to try to make the concept of sustainable development operational. People in the forest sector have been particularly busy in this regard (a review is given later), promoting such concepts as ecologically sustainable forestry.

Thus, the emphasis on indicators of forest sustainability (or of related concepts such as sustainable forest development and sustainable forestry) stems from two sources: (a) the increasing importance of practicing real adaptive management; and (b) the urgency of maintaining or recreating sustainable forests. The public, as collective owner of much of Canada's forest lands, is demanding that forest managers and policy-makers manage forests sustainably. The definition of forest sustainability developed in this project is that a sustainable forest will retain its essential ecological composition, functions, and patterns, which support the full range of societal values, in both the present and the long-range future. How can the managers and policy-makers know when they are achieving this aim? Clearly, they must have a suite of quantitative indicators of forest sustainability, they must set explicit objectives for those indicators, and they must take action to achieve the desired indicator target levels consistent with the objectives.

The purpose of this research project was to develop and test a first-approximation suite of indicators of forest sustainability. The project centred on forest-related values of society not directly linked to economic values, since there is already plentiful information about timber supply and economics, and also to keep the project to a reasonable size. While there seems to have been much activity in the indicator development realm, examination of the situation led me to conclude that the results have not been particularly useful to practicing forest managers, for a variety of reasons. The project entailed a wide-ranging literature review and a stakeholder workshop which provided ideas on promising indicators, and a case study, which assisted in the determination of the feasibility of implementing each proposed indicator. Results from this investigation include: (a) a background to forest sustainability and a rationale and description of the proposed indicators; and (b) the details of the case study which demonstrates the application of the indicators to a working forest, 770,000 ha in size, 40 km north of Thunder Bay.

CHAPTER 2: BACKGROUND

FOREST SUSTAINABILITY - CONCEPTS

Many people feel more comfortable with the concept of forest sustainability than with sustainable development. The latter implies that development will indeed occur as humanity carries on with normal social and technical processes, so the key is to make sure that the quantity and quality of development are such that the various systems that support development are not eroded. Placing either the economy or the environment first sends a powerful message to all concerned about the appropriate focus for concerted action. For many countries, economic development is required for lifting the human condition out of war, ignorance, disease, and famine at the same time as environmental rehabilitation occurs. Some environmental systems or ecosystems require rehabilitation if they are to support continued development of the human species.

Placing the economy first, one interpretation of the Brundtland Report, may be seen as continuation of the status quo of sustained economic growth along with some environmental consideration. This strategy is a danger to society because there are limits to the biosphere's ability to withstand uncontrolled economic growth projected to occur within the next hundred years (Meadows and Meadows 1972; Schumacher 1973; Daily et al. 1994; Wetzel and Wetzel 1995). We have already overshot the limits in some cases, and we are currently reducing our options for global sustainability (Meadows et al. 1992). Major detrimental impacts presently affecting the globe include ozone layer depletion, acid rain, climate change, soil degradation, habitat loss, and species extinctions (Ehrlich and Ehrlich 1981; Brown 1992; McNeely 1992). There seems to be an unwillingness (or an inability) in many countries to recognize, and take effective action to deal with negative effects on the sustainability of the natural resources upon which our economic development, and ultimately our survival, depends.

For relatively healthy economies (recessions and gross public debts notwithstanding) such as those enjoyed in Canada, it seems more reasonable to focus on addressing the dire consequences of the problems created by the classic industrially-based economic paradigm, and "...the reality of ecological limits to material growth..." (Rees 1990). An alternative paradigm is ecological economics which seeks to manage for humanity and the biosphere within one system, rather than the traditional anthropocentric perspective of concentrating on short-term outputs and human benefits (Costanza et al. 1991). Environmental economics agrees with this view, but supports the use of classical economic tools to assist in environmental decision-making (Tisdell 1991). Daly and Cobb (1989) have also criticized the free-market system, as well as globalization, for being the root cause of our crisis, and argue for support and re-building of community to get us on the path to sustainability.

These alternatives represent preferable strategies to prevent further erosion of the integrity of ecosystems, and the quality of life. From this perspective of sustainable development, a number of general principles have been derived (adapted from IUCN/UNEP/WWF (1980), WCED (1987), and ORTEE (1990)):

1) The consideration of a diverse range of values and benefits of natural resources.

2) The maintenance of essential ecological processes and life support systems.

3) Living off the interest produced by natural resources while conserving its capital.

4) Extending planning considerations to several generations into the future.

5) The expansion of spatial consideration of environmental impacts to regional and global scales.

Implementing these principles in the resource sector will require major changes in resource management. A "strategy for sustainable living" has been developed by the IUCN which strives to put principles of sustainability into action (IUCN/UNEP/WWF 1991). A comprehensive approach is required such as the one encompassed in holistic resource management (Savory 1988) which considers the integrity of entire ecosystems, not only individual resources. Ecosystem management is a philosophy or approach to resource management that focusses on ecosystem sustainability, and is receiving increasing attention in the literature (LeMaster and Parker 1991; Aplet et al. 1993; Ontario Forest Policy Panel 1993; Grumbine 1994; Irland 1994; Kaufmann et al. 1994; Maser 1994).

Ecosystem management will require the holistic philosophy and practice of landscape ecology which integrates human activities with the natural environment, functioning within one all-encompassing "total human ecosystem" (Naveh and Lieberman 1994). The complex interactions of biological, physical, and socio-cultural components of landscapes, and the interventions by humans are handled through the application of systems theory. For example, a landscape ecology approach has been applied to forest management planning in British Columbia to create a holistic forest strategy (Hammond 1991). If we are to adopt the encompassing approach of landscape ecology, geographic information systems (GIS) will be an indispensable tool (Haines-Young et al. 1993). GIS have the potential capability to integrate many different types of both spatial and non-spatial data across a range of landscape scales.

"Forests first" is a theme that is beginning to pervade Canadian thinking on sustainable forest development. Witness these statements:

> "Our goal is to maintain and enhance the long-term health of our forest ecosystems, for the benefit of all living things both nationally and globally, while providing environmental, economic, social and cultural opportunities for the benefit of present and future generations" (Anonymous 1992).

> "Our goal is to ensure the long-term health of our forest ecosystems for the benefit of the local and global environments, while enabling present and future generations to meet their material and social needs" (Ontario Forest Policy Panel 1993).

> "Members of the Ontario Forest Industries Association envision a future in which recognition of the inherent value of a healthy forest environment is foremost and in that context, a variety of human needs are met" (Ontario Forest Industries Association 1993).

> "Within a framework of resource sustainability and maintenance of ecological integrity, Ontario will rebuild and sustain a globally competitive forest products industry . . ." (Forest Industry Action Group Steering Committee 1993).

Clearly, Canadians, and Ontarians in particular, want forest managers to work first on securing forest sustainability. What does this mean? It means keeping forests as forest ecosystems (and not agricultural or industrial or other kinds of ecosystems), and secondly keeping forest ecosystems in good condition (Ontario Forest Policy Panel 1993). This is a shift from earlier thinking in forest management, which was dominated for many decades in North America by forest goods and services (SAF Task Force on Forest Health and Productivity 1993). These goods and services reflect the values people place on forests, e.g., timber, water, meat, fur and hides, berries and mushrooms, moss, peat, recreational activities, spiritual and cultural fulfilment, erosion control, wildlife habitat, and many others.

Until recently, forest managers focused largely on wood supply and economic benefits derived from timber. Even in the 1980's, the management of non-timber values was not well integrated with timber management in Ontario (Baskerville 1986; Payne 1990). Non-timber values are often treated as constraints to timber production, and they rarely have had explicit objectives set for them (Duinker 1989). The class environmental assessment for timber management on crown lands in Ontario, recently completed (Koven and Martel 1994), addressed timber management, as opposed to forest management. Perhaps the Crown Forest Sustainability Act enacted in 1994 (Crown Forest Sustainability Act 1994) will improve this situation, with its requirement for identifying indicators of forest sustainability. Without recognition and tracking of important environmental and social values, such as biodiversity and spiritual aspects, there is the risk of damaging a forest's potential. Current planning establishes minimal option sets for the future, resulting from inadequate planning for non-timber values, and thus suffers from a lack of creative solutions to meeting the diverse demands of a democratic society.

Based on the first principle of sustainable development presented above, societal values, or the ways in which people value forests, are one of the keys to the interpretation of the forest sustainability paradigm. A trans-disciplinary framework is needed which is inclusive of the broad range of existing and future values. Enlarging the spectrum of values and benefits included in planning, and thus expanding the indicator suite, widens the window of forecasting environmental impacts, and helps expand the future options. Societal values depend upon critical forest ecosystem features. A critical forest ecosystem feature is a component ar characteristic of a given forest that is an essential contributor to healthy forest ecosystem condition and dynamics. Public forest stakeholders need to be involved in the process of illuminating the full spectrum of societal values.

Values may be activity-related or activity-independent, depending on the nature of the value. For example, wilderness recreation value may be satisfied through wilderness canoeing, while existence value may be satisfied simply by knowing that wilderness areas exist and are fully functional. Specific forest activities depend upon particular critical forest ecosystem features. Settings are the forest surroundings which possess particular characteristics, linked to critical forest ecosystem features, required for the pursuit of forest activities. People pursue opportunities in forests, which are the combination of activities carried out within forest settings, for the realization of values (Manfredo et al. 1983).

Some activities, related to timber management in this project, impose impacts upon critical forest ecosystem features. For example, roads can impact upon wilderness extent, fragmentation of forest landscape, or the level of forest edge. In light of the above reasoning, identification and measurement of the level of critical forest ecosystem features will provide indicators of forest sustainability.

Indicators of Forest Sustainability

A focus on forest sustainability means gauging the condition of the forest ecosystem itself, and not on the uses that people make of forests. A key element of forest condition is its ability to continue to satisfy specific human needs and values over the long term. The following principles about system sustainability apply to forests:

1. Indicators can pertain to a system's productivity, i.e., to the quantities and qualities of goods and services the system provides, or to the system's condition, i.e., its state in relation to desired conditions and its ability to produce specified goods and services.

2. In addition to actions required to take goods and services from a system, management actions may be required to keep systems in a "healthy" condition. This is especially true where pollution, climate change, pathogens, and other stressors are having increasing impacts.

3. Some characteristics of a system have little or nothing to do with its state of "health" or condition. The colour of a car, or length of a person's hair, while descriptive of these systems, have little to do with their system's functionality or health. Thus, some system traits are key indicators of system condition, while others are quite irrelevant.

The goal of sustainable development will remain an empty one unless there are means of measuring progress. Traditional data on the forests of Ontario are provided by the Forest Resources Inventory (FRI) (Appendix 1). Major reports on the forest by the Ontario Ministry of Natural Resources (OMNR) (Appendix 1) have provided descriptions of the forest on a provincial basis, and information on basic management actions of forestry, such as the areas of harvesting, planting, and other silvicultural treatments. These types of data are narrowly defined, and provide only limited information about the environmental impacts of forest-management actions.

Consequently, an over-simplified picture of the forest is presented, and the state of forest sustainability remains unclear.

A number of agencies involved in the generation of sustainable development policy recommend, or intend to develop, indicators of forest sustainability. There have been few significant efforts in the development of such indicators in Ontario (refer to subsequent section). A noteworthy exception is the OMNR's research supporting the recently enacted Crown Forest Sustainability Act, which requires the identification of indicators in each forest management plan for the assessment of forest sustainability (Crown Forest Sustainability Act 1994). The practical indicators proposed in the present project could provide a means to evaluate some of the six criteria of forest sustainability identified in the newly developed forest management planning manual (OMNR 1994a), or may suggest new criteria. A major hurdle in the determination of these indicators is the uncertainty surrounding what exactly constitutes good indicators of forest sustainability. Sustainable development has existed mainly as a concept only, and developing indicators involves placing practical interpretations on the concept. What are we sustaining, and how do we make measurements of our success? This is a challenging task, and calls for the participation of the forestry community and the public to determine the societal values and benefits of the forest to sustain, balanced against the availability and collectability of relevant data.

If we are to achieve forest sustainability, managers will require a broad base of environmental information from which to make sound decisions. Indicators can provide a significant source of this information on forests in the form of quantitative data relevant to sustainability characteristics. Forecasts of indicator performance can be made, the indicators monitored, and environmental impact of management actions and progress toward the development of sustainability measured. Progress reports are submitted to resource managers and the public. Monitoring of indicators provides the feedback which makes adaptive management, including improvement of management actions, possible.

Indicators are most effective when their development includes input of the public to ensure that relevant values and benefits of the forest are considered. In Ontario, effective public participation in developing sustainability is necessary since the resource base is predominantly a public one, and there are many stakeholders with a multitude of resource demands. Therefore another important function of indicators of forest sustainability is to inform the public of the outcomes of forest-management, so they may be knowledgable, active participants in the development of forest sustainability.

In summary, explicit indicators are required if managers are to work toward forest sustainability. Sustainability indicators must focus on forest ecosystem condition. For fully operational use in adaptive forest ecosystem management, identification of the traits to be indicated must be followed by establishment of the ranges within which the indicators must fall for the system to be considered in acceptable condition. This study offers suggestions on the traits to be indicated, the indicators or measures appropriate for these traits, and the operational feasibility of making measurements and calculations for the indicators. Determining acceptable ranges for the system condition indicators will need work in actual management situations or further research. One approach could be to determine the range of natural variability for the indicators, and strive to keep them within this range as forests are used and managed (Thompson 1992; Booth et al. 1993; Ontario Forest Policy Panel 1993; Schlaepfer et al. 1993).

SUSTAINABLE DEVELOPMENT, FORESTS AND INDICATORS

The concept of sustainable development was propelled onto the global agenda by two landmark conservation initiatives: the World Conservation Strategy of the International Union for the Conservation of Nature and Natural Resources (IUCN/UNEP/WWF 1980), and the final report, "Our Common Future", of the World Commission on Environment and Development, also known as the Brundtland Commission (WCED 1987). Canada began to develop its strategy for sustainable development with establishment of the National Round Table on Environment and Economy (NRTEE) in 1988 on the recommendation of the Canadian Council of Resource and Environment Ministers' Task Force on Environment and Economy (NTFEE 1987). The federal government has recently announced the appointment of a "Commissioner of Sustainable Development", whose task it will be to ensure that all federal departments are moving to implement principles of sustainable development in their activities (Copps 1994).

National Initiatives

National Round Table on Environment and Economy

The purpose of NRTEE is to promote the concept of sustainable development in Canada as a basis for developing our social and economic systems (Johnston 1990).

NRTEE promotes cooperation as well as creation of a sustainable balance among social, environmental, and economic pressures. It has criticized current forest management for maximizing product extraction rather than sustainability, for practising poor silviculture which has not sufficiently restocked the forests, and for not knowing how to maintain long-term forest productivity. NRTEE has proposed that sustainable forestry depends on long-term maintenance of industrial wood supply, local employment opportunities, supply and quality of water, recreational opportunities, genetic resources of commercial and non-commercial species, and intact unmanaged ecosystems (Johnston 1990).

Under the auspices of NRTEE, a National Forest Round Table was established, and principles in support of forest sustainability have recently been developed (Forest Round Table on Sustainable Development 1993). While NRTEE is actively looking at sustainable development indicators, it has concentrated effort first on indicators of sustainable energy production and use.

Canadian Council of Forest Ministers

The Canadian Council of Forest Ministers (CCFM), also operating at the national level, released comprehensive national forest strategies in 1987 and 1992 (Anonymous 1987, 1992). A 1987 recommendation included the mandate "...to ensure that forest management goals and practices meet the requirements for sustainable development" (Anonymous 1987). The objective of the 1992 strategy is to account for various forest interests while seeking a practical route to sustainable forestry, and the means to measure its success. In action item 3.5, the 1992 strategy calls on the federal government to "develop a system of national indicators to measure and report regularly on progress in achieving sustainable forest management" (Anonymous 1992).

Canadian Forest Service

The Canadian Forest Service (CFS) of Natural Resources Canada (formerly Forestry Canada) became the first federal department to legislate sustainable development into its Act. To give sustainable development some deeper meaning for forests, one CFS official stated the following:

> "Sustainable development of the forest land and its multiple environmental values involves maintaining, without unacceptable impairment, the productive and renewal capacity and species diversity of forest ecosystems" (Maini 1989).

In addition to having established a national forest data base, the CFS produces both annual reports of forestry statistics and annual comprehensive reports to Parliament on the state of Canada's forests (Forestry Canada 1991, 1992, 1993). In addition to a variety of forest-related information, the two latest reports contain accounts of the "state of the forest" against twelve preliminary indicators: biodiversity, preservation of wilderness areas, forest productivity, environmental quality, forest carbon budget, economic benefits, industrial competitiveness, wood-use efficiency, forest resource control, community and employment stability, public involvement in decision-making, and access to nature for recreational experiences (Forestry Canada

1991, 1992).

In September 1993, the CFS hosted a seminar of CSCE (Council on Security and Cooperation in Europe) Experts on the Sustainable Development of Temperate and Boreal Forests (Mercier 1993). A great deal of attention was paid during the week-long event to indicators, both biophysical (Schlaepfer et al. 1993) and socio-economic (Gordon et al. 1993). In anticipation of this meeting, the Ordre des ingenieurs forestiers du Quebec (OIFQ) and the Canadian Institute of Forestry (CIF) jointly prepared a discussion document of "twenty-eight indicators, objectives and characteristics proposed to lead towards the practice of sustainable forestry" (Ordre des ingenieurs forestiers du Quebec and Canadian Institute of Forestry / Institut forestier du Canada 1993). In this document, some forest sustainability indicators are incidentally identified.

Model Forests

In 1992 under the Canadian Government's Green Plan, the CFS launched the Model Forest program. There are now ten Model Forests across Canada, and several model forests in other countries as well. Model Forests are production forests, of greater than one hundred thousand hectares in extent, where the concepts of integrated resource management and decision-making partnerships are to be implemented (Forestry Canada 1993). The Model Forest Network recently sponsored a workshop on indicators of sustainable development (Anonymous 1993). Papers presented at the workshop covered indicators for ecosystem health (Kessler

1993), forest productivity (Rawlinson and Armson 1993), socio-economic prosperity (Walker 1993), biodiversity (Duinker 1993), and landscape-ecological phenomena (Garman and Bradshaw 1993).

Environment Canada

Environment Canada, as part of Green Plan and State of the Environment Reporting activities, has focused attention recently on ecological monitoring and indicators (Staicer et al. 1993). Workshops were held across Canada to build a national ecological monitoring framework and identify indicators related to ecological stressors. The forest-related indicators identified in this work were comprehensive and related both the forest-management activities and to ecological conditions. An "Ecological Science Centre" will be established in each of Canada's ecozones, linked by the Ecological Monitoring and Assessment Network (Environment Canada 1994).

Canada is participating in the Smithsonian Institution/Man and the Biosphere (UNESCO) (SI/MAB) Biodiversity Program, through Environment and Parks Canada, and other research agencies (Environment Canada 1994). The program aims to establish a global biodiversity network with 300 sites by the year 2000.

Policy Initiatives in Ontario

Ontario Round Table on Environment and Economy

The National Task Force set the stage for provincial round tables to define sustainable development at the provincial scale (NTFEE 1987). The Ontario Round Table on Environment and Economy (ORTEE), a multi-sector task force, developed a sustainable development strategy for Ontario (ORTEE 1990, 1992). Early on, the ORTEE identified several principles for sustainable forest development (ORTEE 1990):

1. The sustainability of the global environment depends on carbon storage, climate stability, erosion prevention, and genetic material preservation.
2. Environmental considerations need to be incorporated into the economic decisions of industry, governments, and consumers.
3. A fair and equitable balance of the needs of all forest users.

Specific strategies consistent with ORTEE's (1990) six general principles of sustainable development include: ensuring the replacement of the growth of forests lost through harvesting and natural disturbances, increased research funding of forest ecology and silviculture, economic diversification of forest uses and products, recycling, conserving representative habitats, and reducing the use of synthetic pesticides.

In 1991, ORTEE established a series of sectoral task forces, including one on forests, each of which was to develop recommendations for the sustainable development of the sector. The Forestry Sectoral Task Force (1992) reported to

ORTEE in March 1992, with a comprehensive set of recommendations. While indicators were not specifically mentioned directly, frequent references to state-of-the-forest reporting suggest the importance of meaningful and incisive indicators of forest sustainability.

One of the two areas of immediate action identified by ORTEE as important for a sustainable development strategy is the development of indicators of progress toward sustainability (ORTEE 1990). The incorporation of indicators with a new proposed state-of-the-environment reporting system for Ontario will be an important tool to evaluate the effectiveness of a provincial sustainable development strategy. Groups identified to develop indicators include universities, research institutes, governments, and industrial associations.

University of Waterloo

Academia has also taken on the challenge of interpreting sustainable development. The Sustainable Society Project (SSP) at the University of Waterloo undertook an ambitious project to define a sustainable pathway for all of Canadian society for 50 years into the future, in environmental, social, economic and political terms (Robinson et al. 1990). The SSP's work has been utilized by NRTEE; its objectives of sustainable development were contributed by the SSP. The project first formulated ecological and socio-political design criteria based on an explicit definition of sustainability (Robinson et al. 1990). The criteria were then used to create scenarios of technological and economic development, in major consumption and resource sectors, with the aid of the simulation model, the "Socio-Economic Resource Framework". Ecological indicator criteria were developed, and work on indicators of sustainable forestry development was to be undertaken (Van Bers 1991).

Conservation Council of Ontario

The Conservation Council of Ontario (CCO), a non-governmental organization, assumed the task of providing ORTEE with recommendations for its provincial sustainable development strategy (CCO 1990). In its objectives for sustainable forestry development in Ontario, the CCO identifies deficiencies in the resource information base, and the overly technical manner in which forest information is available to the public (CCO 1990). The recommended counteraction is one of establishing state-of-the-environment reports for Ontario forests and forestry at two levels: a detailed data base for forest managers, and secondly, a public report based on technical information, presented in an understandable format. The CCO's other four recommended objectives for sustainable forestry in Ontario are (CCO 1990):

1. To promote ecologically sound forest management.
2. The implementation of ecologically and economically sound forest product manufacturing technologies.
3. To promote ecological and social values through forest management.
4. The contribution to a healthy global environment.

Ontario Ministry of Natural Resources

The concrete pursuit of sustainable forestry in Ontario took a major step forward with the May 1991 announcement by the Ontario Minister of Natural Resources of a major sustainable forestry program initiative (OMNR 1991a). The new program is in line with priorities set in the Ontario government's budget statement of May 1991 which cautions that "economic growth is unsustainable if it neglects the environment and the wise management of our resources" (Government of Ontario 1991). The goal of the MNR's new direction in natural resource management is: "To contribute to the environmental, social, and economic well-being of Ontario through the sustainable development of its natural resources" (OMNR 1991b). Two key processes will be to manage for all forest values, and to involve the public in forest management decisions. The pursuit of a means for demonstrating progress toward achieving sustainable development is a high priority for the OMNR.

The OMNR's strategy for improvement of natural resource management began with an independent audit of the provincial boreal forest (Ontario Forest Audit Committee 1992), and continues with a broadly based sustainable forestry program (OMNR 1991a) that includes:

1. Development of a broad strategy to guide forest management long-term objectives.

2. Initiation of community forestry programs in four communities. Consideration and testing of different models.

3. Consideration of alternative silvicultural systems with emphasis on forest ecosystem function, biological diversity, and forest stand dynamics.

4. Development of a protection policy for old growth ecosystems that addresses

social and economic values.

5. Promotion of sustainable forestry on private lands, coordinated with other ministries.

The flagship element of OMNR's sustainable forestry initiative is the policy framework for forest sustainability (OMNR 1994b), which is based on proposals of the Ontario Forest Policy Panel (1993). The framework proposals defined the forests of Ontario broadly, and presented a forest goal, principles for forest, community and resource-use sustainability, strategic objectives for eleven key forest values, and a policy development agenda. In addition, the framework proposal called on forest management and policy to be implemented adaptively, and placed a strong priority on the achievement of forest sustainability in the province. This requires, as explained above, the identification and use of indicators of forest sustainability, and the Ontario Forest Policy Panel (1993) urged their development especially for forest biodiversity.

Summary

Concepts and indicators of sustainable forest development in Ontario and Canada have been given increasing attention during the past ten years. Despite all the attention, indicator development is still in its infancy, to say nothing of their virtual absence presently in actual application. This observation prompted an applied approach to the problem, with the objective of helping forest managers and owners move from ethereal discussions to on-the-ground tracking of progress in achieving forest sustainability.

CHAPTER 3: METHODS AND PRACTICAL FRAMEWORK

The following is a set of premises or assumptions which acted as guides during the process of developing and applying forest-sustainability indicators. Below this is a description of the process utilized in the project.

ASSUMPTIONS

1. Indicators of forest sustainability are most useful if applicable at the level of the forest management unit.

Indicator development research was focussed on the northern forested Crown lands of Ontario (although the general concepts are probably applicable in other forest regions and for other forest types). The Crown forest lands used for timber production are divided into administrative units which are managed as sustained-yield units. Such units range in size from less than a hundred thousand hectares to more than one million hectares. They are comprised of hundreds to thousands of stands, as defined in Ontario's forest resource inventory (FRI). The rationale for targeting indicator development at the forest management unit (FMUs) level is as follows. Smaller areas of land would be inappropriate because natural processes such as fire and windthrow can create huge fluctuations in stand-level indicators such as overstory structure. In the boreal forest especially, stand overstories are temporary entities, but the forest as a whole persists on a broad scale. Moreover, forest condition is largely a function of landscape patterns, which must be examined across large units of land.

For the boreal forest, this means a scale on the order of many thousands of hectares.

A key problem arises because administrative units rarely correspond to ecological units. Under such circumstances, analysts are urged, where possible, to include adjacent forest areas in their analysis where these would improve the ecological interpretability of results.

As indicated above, indicators are frequently applied at provincial and national scales. It should be possible to aggregate up to any desired level a consistent set of indicators for forest sustainability that are designed for the level of the working forest. This is because it would often be a simple additive process up to the higher scale, with the exception of some spatial measures. However, the reverse may not be the case; where indicators are developed for the provincial level, it may not be possible to scale them down to the management unit level. It is likely not possible to assign values to sub-units of a province from a provincial value, or where values were aggregated to a provincial scale without regard for spatial identity.

2. Indicators must be measurable for present forest condition, and predictable for future forest condition under realistic alternative management scenarios.

To be part of adaptive forest ecosystem management, indicators must be both measurable in the field and predictable in response to a wide range of alternative management strategies. Predictability is crucial for analysts to be able to inform the decision-making process, and measurability is crucial for the learning that occurs when one discovers that expectations and reality diverge (Duinker 1987; Baskerville 1993). A reasonable time frame over which to make indicator forecasts in forest-management planning would be a minimum of 50 years. The effects of today's management actions will be experienced for at least such a time period.

3. Indicators of forest sustainability must pertain to some biophysical traits of the forest, that can be objectively measured.

Forest sustainability is a function of forest condition. The forest is defined here as an ecosystem, or collection of ecosystems. Management actions are not part of the forest system, but are inputs to it. Thus, actions such as planting are not indicators of forest sustainability. Similarly, goods and services of the forest are not part of the forest system, rather are outputs from it. Thus, timber production for example is not an indicator of forest sustainability. Forest-based businesses are also not considered here to be part of the forest ecosystem. This bounding of forest ecosystems is made for three reasons: (a) for simplicity; (b) to focus the concept of forest sustainability on natural ecosystems; and (c) to emphasize that forests are quite sustainable without any human activities or interventions in them.

4. A simple yet comprehensive set of indicators, each of which provides useful information to stakeholders and for which data are relatively accessible, is the most appropriate entry point.

Simplicity is paramount in developing indicators of forest sustainability because forest managers, owners and stakeholders, and indeed the general public, all have to understand, accept, apply, and interpret them (CCO 1990; Henderson 1991; Duinker 1993). It is vital for indicators to relate to the values of these groups of people, so that indication of forest sustainability has real meaning and is not just an exercise in esoteric description. Data availability is critical, for an indicator that cannot at present be measured for feasibility or financial reasons, is just a good idea for future use, or for current research - it will not help assess forest sustainability today.

5. The Ontario Forest Resource Inventory must serve as the initial data set for indicator applications.

For the time being, the only comprehensive, mapped data describing any of the dynamic elements of forest ecosystems across Northern Ontario is the FRI (Watt 1994). Maps often exist for the relatively stable elements of forest ecosystems, e.g., geology, landforms, topography, soils. However, much of the interest in forest sustainability has to do with flora and fauna. Forest ecosystem classifications have been developed for Northern Ontario (e.g., Sims et al. 1994), but few if any forests have yet been mapped according to these classifications. Thus, the FRI must be used, but analysts must be keenly aware of its purposes and limitations (Kapron 1994; Watt 1994).

Another feature of indicators of forest sustainability is that not only are the levels of indicators of interest, but the spatial distribution of indicator values are also important. To calculate many of the indicators likely to be found useful, a digital, spatially referenced FRI will be needed. A geographic information system (GIS) is needed also, to perform many of the indicator calculations.

6. The forest region to which these indicators are relevant is the boreal forest.

The ecological principles and social values used to justify indicators, and the measures themselves, should also be generally applicable to the Great Lakes/St.Lawrence forest region of Ontario. However, indicator target levels would need to be tailored to suit each region.

A DEVELOPMENTAL PROCESS

The search for indicators began with a comprehensive literature review, a task which continued to project completion. The emphasis of the literature search was sustainable development and forests, and also literature from other disciplines in social sciences and natural resources, looking for documentation of ways people value forests, and ways people describe forests when they comment on forest condition or management.

A large suite of indicators was initially created, within a matrix format, with little recognition for practicality given today's technology, based on the background research as well as personal experience in forestry issues (Appendix 2). A preliminary suite of values which the public deems important with respect to forests was determined. Then forest ecosystem attributes deemed to be necessary to ecosystem function, and to satisfy various values were identified. They were derived by asking: What feature of the forest ecosystem, if altered, would affect particular societal values and ecosystem functions? Indicators were determined, at the intersection of values and forest attributes, in answer to the question: What are measures of the forest ecosystem attribute which can indicate the ability of the forest to satisfy a publicly-held value, or to fulfill an ecosystem function?

Stakeholder and interest group input were solicited by circulating the preliminary indicator suite. The main result of this process was expansion of the indicator list. Interest groups that I attempted to involve in this process included environmental, community, native, recreational, tourism, and sporting groups.

The comprehensive indicator suite was then rogued to those expected to be measurable in the foreseeable future. A small workshop was held in Toronto in October 1992 to address the technical aspects of indicator implementation (for a list of workshop participants see Appendix 4). This assisted in setting priorities for indicators which would actually be developed into quantified measures and demonstrated as an application. Indicators set aside at this stage are reported in Appendix 5.

APPLICATION IN AN ONTARIO BOREAL FOREST

Case Study Forest

The choice of an Ontario boreal forest to be used as a case study forest was directed by a number of criteria. It was important that there be a variety of forest users, representing a diversity of forest-related values. The presence of significant mature forest, and wilderness conditions, with forest management activity in the area, resulted in a diversity of conditions useful for testing of indicators within the Spruce River forest. The availability of current digital forest inventory data allowed the measurement of a broad range of indicators.

The Spruce River forest is located approximately 40 km north of Thunder Bay, Ontario, and its southern limit is situated 40 km north on the Spruce River Road from the Trans-Canada highway (Figure 1). An FMA was initiated for this forest in 1981 with Abitibi-Price. The forest is 740,000 ha in total size, and its shape consists of a main body with two major arms. The forest was sub-divided into four regions for this study to facilitate data analysis, and comparison of indicators between different parts of the forest. The forest cover is dominated by jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) in the north, and mixedwood in the south. The level of logging in the forest in recent years has been ca. 530,000 m^3/yr. A major burn in the northern section, which occurred in 1980, covers 89,000 ha of the Spruce River forest. The major road network runs in a southeast to northwest direction.

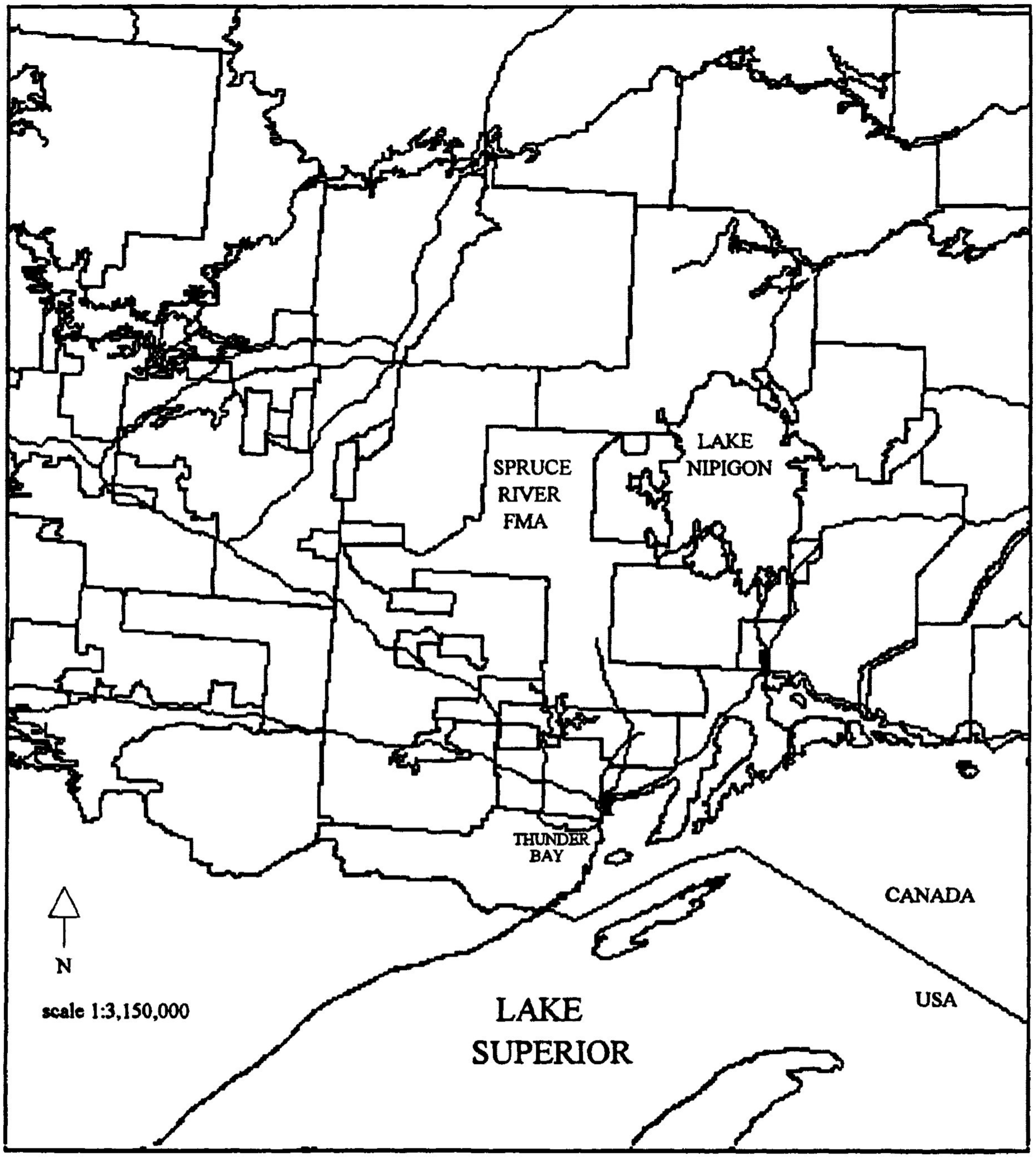


Figure 1: Location of the Spruce River forest within northwestern Ontario.

Preparation of the Forest Dataset for Indicator Measurement

The digital dataset for the Spruce River Forest resided on the GIS facilities of the Chair in Forest Management and Policy, and LU-CARIS, Lakehead University. The dataset, at the outset of this project, was in a format that had been used for timber management planning by Abitibi Price Inc. A considerable amount of data preparation was required to create a dataset suitable for the measurement of forest sustainability indicators over the entire FMU landscape.

The original forest dataset existed in two adjacent UTM zones (15 and 16). The zones' coordinates had been shifted so that the UTM zones did not lie beside one another. To address this difficulty, the two halves of the dataset were positioned adjacent to one another in a precise way, in one UTM zone. The disadvantage of this approach is that there is a loss of positional data in zone 15.

The original dataset was also partitioned by individual 10,000 ha Ontario Basic Map (OBM) basemaps, as is standard for the FRI system in Ontario. There are 42 full OBMs, and 66 partial OBMs. All OBMs were joined to create one contiguous dataset across the entire forest.

The dataset, in its original form, was current to different years, and some data were incomplete. The FRI data were current to 1991, while cutover data were current to 1985. Stand data were missing for 24,000 ha in the forest layer which were determined to be cutovers, and for a large burn in a northern section of the forest which occurred in 1980. All data were configured to 1985 so that all data layers were consistent. In the case of the missing stand data for cutovers and the burn, data were assigned according to regeneration tables based on estimates of regeneration success

(Kromm 1993) (Appendix 6).

The way in which a forest landscape is classified under the FRI system is not adequately representative of ecosystem patterns and processes on the ground. A more ecologically realistic classification of the Spruce River forest landscape was created and used. FRI "forest stands" were amalgamated into more broadly defined "forest cover types" (e.g. spruce/pine or poplar/conifer) for use in some indicators. It might be appropriate in other cases for analysts to consider using FEC data for forest re-classification.

Quantification and Testing of Indicators

How can the qualities of a particular forest attribute be quantified into a practical indicator? My impressions of the characteristic features of forest sustainability were tempered by the pool of digital data commonly available in the FMUs of Ontario. Not all desirable indicators could be formulated due to a lack of required data in digital format. If a given forest attribute was determined to be a significant component of judging forest sustainability, and data were available for the attribute, then a first approximation of a measurable indicator was developed.

Once the precise specifications for indicators were determined, algorithms were created. Occasionally deficiencies in the data were discovered at this point. Further data preparation and manipulation was often required to enable calculation of the indicator.

The algorithms were then run on the GIS, using the appropriate data from the Spruce River forest dataset, to produce data in tabular form on which the indicators would be based. Graphs and maps were created and analyzed to determine if a particular indicator was accurately depicting the forest. A new configuration of an indicator was sometimes discovered as a result of making this first attempt at calculating and displaying results for an indicator. The specifications for the indicator were then improved or fine-tuned, and the algorithm adjusted accordingly. This iterative process of testing and improvement was ongoing until I was satisfied that the indicator accurately represented and interpreted the landscape, within data constraints. The process was halted once a satisfactory first approximation was achieved, since there was a time constraint on each indicator related to the goal of developing indicators to cover as full a spectrum of sustainability factors as possible.

CHAPTER 4: FIRST-APPROXIMATION INDICATORS FOR FOREST SUSTAINABILITY

The first-approximation for 13 indicators for managing for forest sustainability is reported here. The indicators are explained and justified, and ideas are developed on how they ought to be calculated, interpreted and displayed for use in forest planning. All developed indicators were not tested on the Spruce River Forest, nor was the forecasting aspect of the application carried out. There is no case study test summarized below for the naturalness indicators (3 and 4) nor for the marten indicator (11). In addition, the tests for both the remoteness and size-of-wilderness indicators (1 and 2, respectively), and the tests for both old-growth indicators (8 and 9), are discussed below under single headings (below the second of each indicator pair).

INDICATORS RELATED TO WILDERNESS

Wilderness is of great significance to Canadians, and is part of our heritage and identity (Miller 1992). Wilderness has been defined as ". . . a wild roadless area where those who are so inclined may enjoy primitive modes of travel and subsistence . . ." (Leopold 1925). Wilderness can be experienced in two ways (Hendee 1990): (a) directly, as visitors experience things like education, therapy, and spiritual renewal; and (b) indirectly, such as through film, print, or contemplation. Noss (1991) has argued that wilderness is the foundation of biological conservation.

There is a general lack of research, and application of results, on the social values of the forest environment in Ontario (Payne 1990), and indeed elsewhere (Vining 1991), and thus a lack of guidance on how to create forest-sustainability indicators from a wilderness point of view. However, I propose here that the wilderness value of a forest can be gauged using three indicators: (a) remoteness (distance from active roads); (b) size of wilderness area; and (c) degree of forest naturalness.

1. Remoteness

Concept and Rationale

Remoteness is essential for wilderness experience. Remoteness is a key component in classifying U.S. wilderness according to the Recreation Opportunity Spectrum (ROS) (USDA Forest Service 1990). Many values related to remoteness and wilderness depend upon peace, solitude, and freedom from human intervention, including: reverence for nature and spiritual value, therapeutic and character building value, knowledge value, and wilderness-recreation values (Rolston 1986; Payne 1990). Improving road networks and making access more convenient to a greater number of people can threaten these many unique wilderness benefits (Hendee et al. 1990). The most important forest attribute to the northern Ontario tourist industry is remoteness (OMNR and OMTR 1989). Nearby roads are reported to decrease the quality of experience for visitors to remote tourism camps in Northwestern Ontario (Duinker 1991; Haider and Carlucci 1992) and are seen to be a real threat to the remote tourism industry (Payne 1991).

The largest impact on remoteness is indeed roads. Roads dissecting tracts of forest wilderness make the wilderness more accessible and less remote. The impact of a road on forest remoteness extends well beyond the road itself. Forest remoteness is eroded within several kilometres of active roads. Remoteness may vary with class of road, depending upon the road characteristics and forest ecosystem feature under consideration.

Remoteness is also relevant to human- and/or predator-sensitive species such as woodland caribou. Roads provide increased access to caribou for hunters, and possibly for predators as well (Darby and Duquette 1986; Stevenson 1986; Kansas et al. 1991), in addition to vehicular traffic disturbances to the wildlife species (Hyer 1993, pers. comm.).

Remoteness is defined as the distance of a given hectare of forest from a road or road network. A classification of remoteness grades, compatible with the remoteness classification scheme of the ROS (USDA Forest Service 1990) is proposed (Table 1). Grade of remoteness improves with increasing distance from a road network.

Scant attention has been paid to remoteness-related values in contemporary forest management, partly because of a dearth of social science research focused on forests and their use (Payne 1990). Also, roads are seen by forest managers as essential to timber management, and planning for remoteness as unnecessary.

Table 1: Remoteness class definition by distance-to-road.

Remoteness Class	Distance to Road
5	20m - 200m
4	200m - 1km
3	1km - 3km
2	3km - 5km
1	> 5km

Considering that much of the Crown forest in Ontario is designated for industrial timber management, it is critical to gauge the impacts of timber management operations on the remoteness of all parts of the forest from a regional level, and therefore to determine the forest's capability to satisfy wilderness values.

Structure of the Indicator

A remoteness classification is proposed consisting of five classes of land, at different minimum distances from roads: 20 m, 200 m, 1 km, 3 km, and 5 km (Table 1). All three classes of road were lumped together for inclusion in the remoteness calculation due to their ratings of high to medium-high for "access" and "landscape/scenic beauty impacts" (Table 19). A problem arises in being able to determine whether mapped roads are actually being used. Sometimes roads are gated to restrict vehicular use, and unneeded roads are usually not maintained, and therefore may become impassable with time. Unless specific information is available to the contrary, a first-approximation analysis should probably include all mapped roads.

A histogram or table can be used to show the absolute or relative (percent) area of the forest in each remoteness class, and in each contiguous roadless area size class (Tables 2 and 3). Maps reveal the spatial relationships of the remoteness zones.

Data and Analysis Requirements

data format: vector*
data for entire forest contained in the same data coverage
coverages: roads, forest
buffering function (along with other standard GIS functions such as overlay

Table 2: Size of wilderness by remoteness class and roadless area size class for the Spruce River forest.

REMOTENESS PATCH AREA (ha)	AREA OF DISCRETE PATCHES (ha) REMOTENESS CLASS (km)					TOTAL	% OF TOTAL
	0.02 - 0.2	0.2 - 1	1 - 3	3 - 5	> 5		
1 - 100	55,763.6	19,841.2	1,062.2	114.5	189.3	76,970.8	10.4
100 - 1000	64,080.7	59,541.1	11,754.8	3,073.7	0.0	138,450.3	18.7
1000 - 10000	46,193.5	121,338.1	58,371.6	15,906.4	11,804.8	253,614.4	34.2
> 10000	0.0	18,224.0	91,489.2	50,691.5	112,095.4	272,500.1	36.7
TOTAL	166,037.8	218,944.4	162,677.8	69,786.1	124,089.5	* 741535.6	100.0
% OF TOTAL	22.4	29.5	21.9	9.4	16.7	100.0	

* 24,000 ha of unclassified cutover not included

Table 3: Number of discrete wilderness patches by remoteness class and roadless area size class for the Spruce River forest.

REMOTENESS PATCH AREA (ha)	NUMBER OF DISCRETE PATCHES REMOTENESS CLASS (km) 0.02 - 0.2	0.2 - 1	1 - 3	3 - 5	> 5	TOTAL	% OF TOTAL
1 - 100	3,380	1,731	30	5	115	5,261	89.7
100 - 1000	260	206	31	5	0	502	8.6
1000 - 10000	21	43	19	6	2	91	1.6
> 10000	0	1	3	3	2	9	0.2
TOTAL	3,661	1,981	83	19	119	5,863	100.0
% OF TOTAL	62.4	33.8	1.4	0.3	2.0	100.0	

* Note: here I am reporting only my own preference for analytical work in this study. Other analysts may find it preferable to use data in raster format, or they may wish to experiment with both and choose a format thereafter.

2. Size of Wilderness Tracts

Concept and Rationale

Size of wilderness refers to the areal extent of a given forest parcel, classified as wilderness of one quality or another. The size of a wilderness tract can determine its wilderness quality. Greater peace, solitude, and freedom from significant human intervention are experienced with increasing size of wilderness tracts. In addition, the size of wilderness areas may be a critical habitat attribute for area-sensitive, large-mammal species (Diamond 1975; Whitcomb et al. 1976; Newmark 1987) such as caribou or wolves. Therefore, measuring the size distribution of wilderness tracts across a forest landscape gives a picture of the forest's wilderness character. The lower size threshold for both viable roadless wilderness areas in the U.S. (Wilderness Act 1964), and for wilderness zones in parks in Canada (OMNR 1992) has been established to be 2,000 ha .

Structure of the Indicator

Wilderness size is closely related to remoteness, as it is also a measure of the extent of human intervention in the form of roads, and other timber management activity. In the forest landscape managed for timber, the wilderness patches are defined by the roads bounding them. Once remoteness (i.e., distance - see above) contours are placed around the road network, and zones of remoteness are determined, then the size and number of patches in each remoteness grade can be calculated (Tables 2 and 3). Maps, by region and for the entire forest, reveal the size distribution of remoteness zones across the forest.

Data and Analysis Requirements

data format: vector
data for entire forest contained in the same data coverage
coverages: roads, forest
buffering function

Remoteness, and Size of Wilderness Tracts: Case Study

Analysis for Case Study

Within the remoteness classification scheme, all roads in all three road classes were assumed to have the potential to be accessed. Roads were buffered by the five distances. The resulting patchwork was classified into the five distance-to-road (remoteness) classes. The absolute and relative (percent) area of the forest in each remoteness class, and in each remoteness patch area size class, were tabulated and displayed by histogram (Table 2 and Figure 2). The number of discrete wilderness patches was similarly tabulated and displayed (Table 3 and Figure 3). The remoteness zones of the forest were mapped to reveal their spatial relationships.

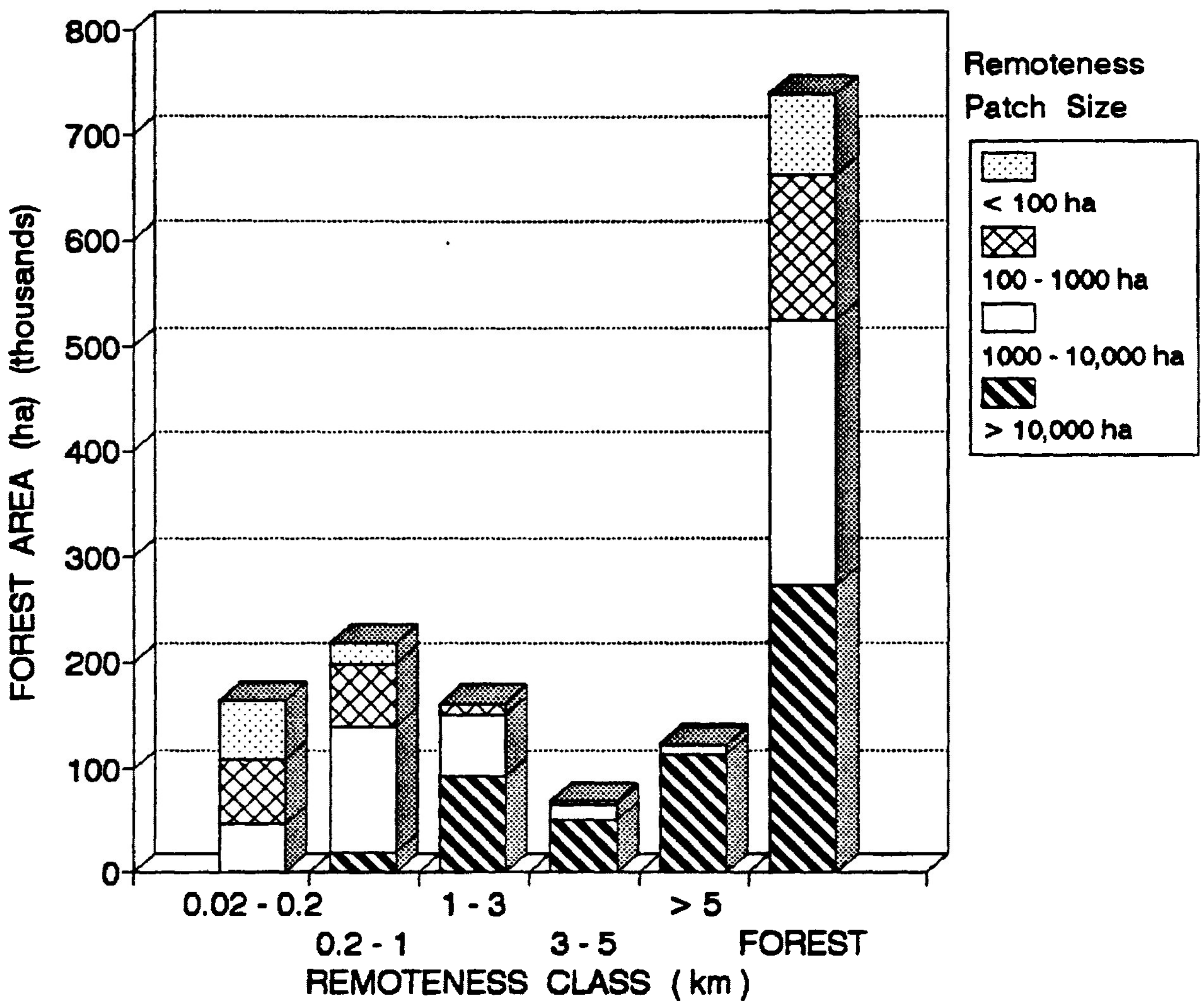


Figure 2 : Distribution of forest area within remoteness classes and size of remoteness patches for the Spruce River forest.

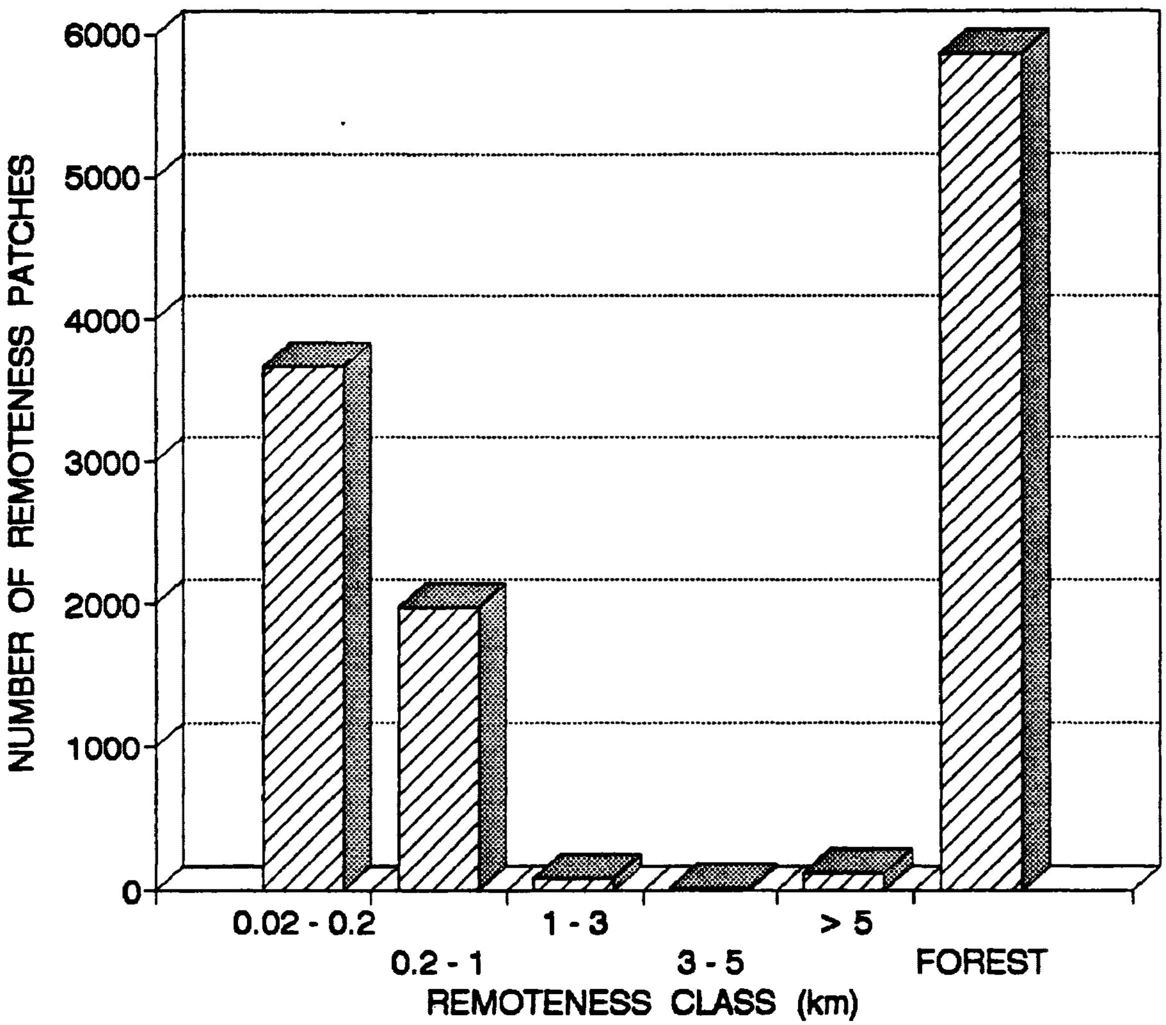


Figure 3 : Number of discrete remoteness patches within remoteness classes for the Spruce River forest.

Results

Over half of the Spruce River forest is less than 1 km from roads (Table 2 and Figures 2 and 4). There is significant area in the smaller remoteness patches (< 1000 ha) of 215,420 ha or 29% of the forest. Most of the area (50% of the forest) of smaller patches (< 10,000 ha) occurs in the low remoteness classes (< 1 km from road). Most of the area (34% of the forest) of larger remoteness patches (> 10,000 ha) occurs in the upper remoteness classes (> 1 km from road).

Observations of the map of the Spruce River forest (Figure 4) indicate a north to south trend in remoteness. Larger areas of the higher remoteness classes in the largest remoteness patch sizes occur in the north, and larger areas of the lower remoteness classes in smaller remoteness size patches are found in the south.

The vast majority of the number of patches (95% of forest total) occur in the lowest remoteness classes (< 1 km) and in the lowest remoteness patch area size classes (< 1000 ha) (Table 3 and Figures 3 and 4). Ninety percent of the number of patches are < 100 ha in size, and 96% of the total number of patches are less than 1 km from a road. Twenty two percent of the Spruce River forest area is greater than 3 km from roads in remoteness patch area of greater than 10,000 ha, and occurs in a total of five patches. There is also a north/south trend, to some extent, in the number of discrete remoteness patches (Figure 4). In the north there are fewer discrete patches in the lowest remoteness classes. In the south there are no patches in the most remote class (> 5 km).

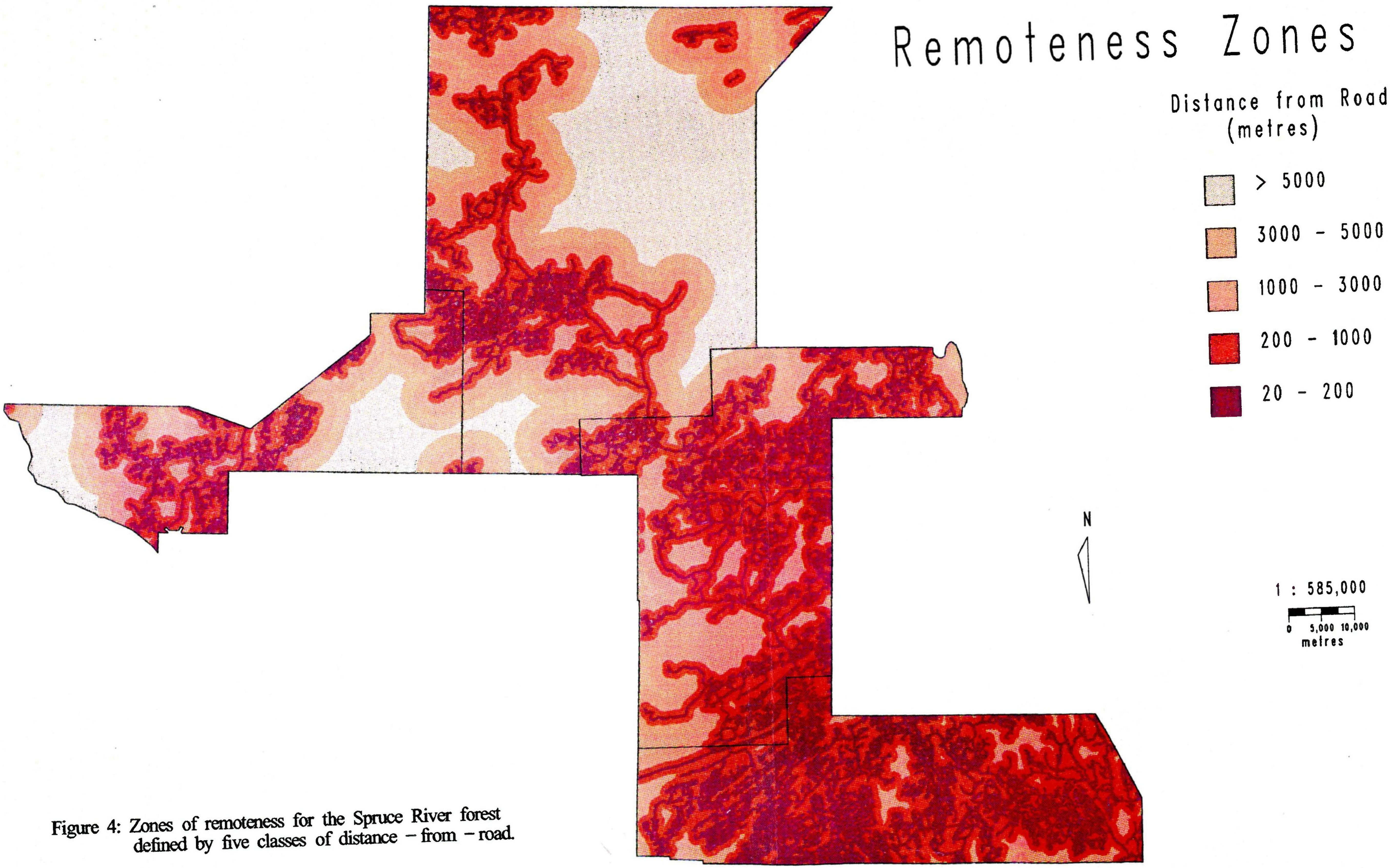


Figure 4: Zones of remoteness for the Spruce River forest defined by five classes of distance – from – road.

Interpretation and Evaluation

The remoteness of the Spruce River forest has been reduced by roads built for timber management purposes. From the original natural condition of an absence of roads, or 100% of forest area > 5 km from roads, the trend over time is a reduction in area within the uppermost remoteness classes, and increasing area in lower remoteness classes. In forest planning, a target could be set for a minimum level to be maintained in the upper, less abundant, remoteness classes in specific regions throughout the forest.

The size of wilderness patches, as defined by remoteness class boundaries, has been reduced by the expanding network of roads in the Spruce River forest. As defined here, the forest was once a large wilderness area. The number of remoteness patches has progressively increased as the areas of individual remoteness patches have decreased. Remoteness patches less than 2,000 ha in extent are not considered to be viable tracts of wilderness. A target could be set in forest planning for a minimum level of area to be maintained in remoteness patches greater than 10,000 ha, and within a minimum remoteness level.

In the application of the remoteness indicator, it may be desirable to designate different levels of remoteness based on road class. For example, if human- or area-sensitive wildlife species, such as caribou, were specifically of interest, then tertiary roads would be rated higher in remoteness, and highways would be rated lower in remoteness.

3. Naturalness - Timber Management and Existence Value

Concept and Rationale

Significant segments of the public view timber management as having degrading effects on forest naturalness, related to their sense of the importance for the forest to exist and function in a natural state (Rolston 1987, from environmental philosophy; Brand 1992, from sustainable development, and forest policy implementation experience). It is proposed here that for many, the effects of timber management treatments such as timber harvests and artificial regeneration would diminish as a stand ages, as long as the treatments mimic natural processes and patterns. Thus, the longer ago that timber management treatments occurred in a forest stand, the more "natural" the stand may be said to be. This is especially the case in the boreal forest following clearcut harvesting, because stands artificially regenerated to conifers are frequently mixedwood to some degree, and when they are essentially pure, they have apparent characteristics similar to natural pure stands of the same tree species.

Given this assertion, I propose that a general stand age can be identified after which any post-harvest forest stand would be considered essentially "natural" by a lay person. The point of this indicator is to track the area of the forest in a more natural state, versus other areas less natural (i.e., still bearing obvious effects of management treatment). Over time, one could determine whether the forest were becoming more or less natural according to the existence criterion for naturalness.

Structure of the Indicator

A scheme is proposed here in which there are three naturalness categories:

(a) natural forest, in which no timber management treatments (including harvest and regeneration silviculture) have taken place;
(b) treated stands greater than the prescribed age for naturalness; and
(c) treated stands younger than the prescribed age.

Using this scheme, all stands in categories (a) and (b) would be considered natural, and those in (c) as unnatural (i.e., where the effects of treatment may still be great). A useful prescribed age for Ontario's boreal forests might be 40 years. Boreal forests at age 40 are beginning to possess traits typical of mature forests, and effects of clearcutting are no longer significantly evident, as long as treatments mimic natural processes and patterns. Future research will be required to invalidate the accuracy of this proposed naturalness-related age criterion.

Applying these classes may be problematic. Forest inventories may not have clear and unambiguous data about stand age and origin. One might be forced to make simplifying assumptions when applying this indicator to a current forest inventory. For example, unless data exist to indicate otherwise, assume all stands having a year of origin equal to or later than the beginning of clearcut timber harvesting in this forest are treated stands, and thus unnatural until they reach age 40. This means that no stands under 40, unless data show otherwise, originated following windthrow, insect infestation or wildfire.

Results of applying the naturalness indicator to a forest can be displayed in tabular, graphical or map forms (e.g., Table 4). Also useful are maps of the entire forest, with basemaps classified by percent area in timber management.

Table 4: Forest area under timber management by basemap and region.

Region/Basemap (BM)	Area (ha)		
	Natural Forest (no timber management)	Timber Management (from present)	
		< 40 years	> 40 years
Region 1: BM 1			
BM 2, etc..			
Total			
Region 2: BM 1, etc..			
Forest Total			

Data and Analysis Requirements

vector data format
data for entire forest contained in the same data coverage
coverages: forest, cutover update
stand ages, cutover ages

4. Naturalness - Forest Patch Size and Configuration Diversity

Concept and Rationale

It has been shown for the boreal forest that different landscape patterns emerge, with the combined effects of fire suppression and clearcut timber harvests, compared to natural landscape patterns due to natural disturbances that are allowed to run their course (Suffling 1991; Thompson 1992). These patterns are particularly evident in the spatial configuration of various stand types and ages. Forest cover and age patches resulting from timber management are smaller and less variable in size (a few hundreds of hectares), compared to natural disturbance patches which are in the range of a few hectares to thousands of hectares (Thompson 1992). The distribution of patches resulting from timber management are often sequential, as opposed to the random pattern from natural disturbance (Thompson 1992). Given the emphasis placed today on trying to emulate natural patterns when timber management treatments are implemented (e.g., Thompson 1992; Booth et al. 1993; Ontario Forest Policy Panel 1993; Schlaepfer et al. 1993), forest managers and stakeholders will want to gauge the degree to which timber management is indeed matching natural patterns.

I propose that a useful measure of naturalness of forest landscape pattern is found in forest patch sizes and configuration. The naturalness of patch size and configuration is determined by the differences in forest patch size distributions and landscape configurations between tracts of natural forest, and tracts in which management treatments have taken place (harvesting and regeneration). Natural stands would include all those known to have regenerated following natural disturbance, plus all those whose year of origin is older than the beginning of clearcut harvesting in the forest in question.

Structure of the Indicator

The forest stands would be divided into two groups: (a) stands of treatment origin, and (b) all other stands, by definition of natural origin. Stands need not be strictly defined as in standard forest resource inventories, but can be redefined as the analyst sees fit. Once appropriate forest stand size classes are determined, the (a) area, and (b) number for each class for each group would be calculated (see Tables 5, 6 and 7). Maps would reveal patterns of patch size and configuration across the landscape.

Data and Analysis Requirements

data format: vector
data for entire forest contained in the same data coverage
coverages: forest, cutover update
stand data: stand ages, cutover ages

Table 5: Forest stand or patch size classification.

Size Class (ha)	Number of stands	% of Total Stand Number (%)	Area (ha)	% of Total Area (%)	Cum. % Area (%)
0-19.9					
20-39.9					
40-59.9					
60-79.9					
.					
.					
.					
Total or Average					

Table 6: Total area in each forest patch size category for natural patches and timber management patches.

	Total area (ha)				Grand Total
Description/Age (years)	Forest Patch Size (ha)				
	0-10	10-100	100-1000	>1000	
Forest Patches/ > 40					
Burn Patches/ < 20					
Cuts / < 40					
Grand Total					

Table 7: Number of forest patches in each forest patch size category for natural patches and timber management patches.

Description/Age (years)	Number of Forest Patches: Forest Patch Size (ha) 0-10	10-100	100-1000	>1000	Average
Forest Patches/ > 40					
Burn Patches/ < 20					
Cuts / < 40					
Average					

INDICATORS RELATED TO BIODIVERSITY

Integrating biological diversity conservation and resource management is critical to forest sustainability since biodiversity cannot be conserved in the small proportion of the landscape set aside as parks (Probst and Crow 1991). The goal of managing for biodiversity is to "ensure viable populations of all native species characteristic of the management area" (Hunter 1990). Biodiversity must be measured at the appropriate scale since its long-term maintenance is dependent upon management focused on regional biogeography and landscape pattern rather than local concerns (Noss 1983). A holistic landscape approach, which incorporates ecosystem processes and patterns at various temporal and spatial scales, is essential to maintaining and enhancing long-term integrity of biodiversity (Naveh and Lieberman 1994; Urban et al. 1987; Turner 1989).

A commonly used definition of biodiversity comes from the U.S. Office of Technology Assessment (1987): biodiversity is "the variety and variability among living organisms and the ecological complexes in which they occur". Biodiversity has many facets. Noss (1990) presented a hierarchical characterization of biodiversity, with the three aspects of compositional, structural, and functional biodiversity nested within an outer earth sphere. There is, in turn, a hierarchy within each of these aspects down through four scales: (a) regional landscape (or forest, for our purposes); (b) community/ecosystem (stand); (c) population/species; and (d) gene pools.

Bunnell (1990) presented eight reasons why forest managers should take biodiversity seriously in developing and implementing forest management plans:

(a) aesthetic values - people like to perceive biodiversity via the senses;

(b) moral (religious) values - conservation of species is a moral obligation;

(c) economic values - goods and services provided by wild species to humans;

(d) future values - our ignorance about wild species globally is so profound that many future values now unknown will emerge;

(e) practical values - human survival on earth depends on conservation of wild species;

(f) indicator values - changes in forest biodiversity may signal more serious changes to come;

(g) blueprint values - ecosystems where biodiversity has been conserved may indicate how we must reconstruct ecosystems where biodiversity has been eroded;

(h) the public wants it - the public, which owns the vast majority of Canada's forests, has said over and over again, directly and indirectly, that it wants forest biodiversity to be conserved.

Consider two key departure points for proposing indicators for forest biodiversity:

1. The approach must be simple:

> "It is imperative that the approach to managing land with (bio)diversity in mind be kept as simple as possible."
> (Salwasser et al. 1986)

Complex approaches will be unappealing to managers and stakeholders alike. A simple approach can be as technically legitimate as any complex and more comprehensive approach, and indeed more powerful because of higher potential understanding and acceptance by those using it.

2. Among-stand diversity is the place to start. The following quotes support this:

> ". . . conservation of much habitat can be accomplished by ensuring a balanced mix of forest ecosystems reflecting a full range of dynamic forest conditions."
> (Miramichi Pulp & Paper Inc. 1992)

"The only way to conserve a breeding place for all these birds in perpetuity is to ensure a continuing supply of forest ecosystem types." (Welsh 1992a)

". . . managing for biodiversity at coarse-scales (regional), would, to a degree, also manage for biodiversity at finer scales (local)." (Perera 1992)

". . . concerns about biological diversity have little to do with numbers of species, but rather focus on native species that are most threatened by human activities. Saving species is impossible without saving the ecosystems of which they are a part and on which they depend; thus, there is increasing emphasis on conserving whole ecosystems so that species can also be conserved." (Society of American Foresters Task Force 1991)

"Maintenance of a continuing supply of all natural forest ecosystem types is the foundation for the conservation of biological diversity and sustainable development." (Booth et al. 1993)

Ecosystems are best understood as living and non-living structures, their functions (processes), and the interactions among them (Diaz and Apostol 1992). For purposes here, let us assume that stands represented in the FRI can be viewed as ecosystems, since stands are the only identifiable units. More meaningful ecosystem units can be created by dissolving stand boundaries. However, the boundaries of these newly defined ecosystems must be ultimately delineated by stand boundaries. To track the diversity of stands in a forest, one can classify stands as to their age, type, size and shape (let us call these stand traits), and then examine each classification scheme in terms of the richness, evenness, and spatial distribution of members in the class (let us call these diversity measures). One can also do this for the boundaries between ecosystems, or edges. "Significant edge" is defined here as a linear feature where two significantly different ecosystems border each other.

Diversity measures can be analyzed and displayed in a variety of ways. Histograms of area and number of stands or edges in each class for each stand or edge trait are convenient for the display of richness and evenness, and maps are best for displaying spatial distribution.

Richness refers to the number of classes in which there are stands or edges (Hunter 1990; Burton et al. 1992). For example, a forest with eight 20-yr age classes (i.e., stands of all ages up to 160 yr) is richer than a forest with four age classes (e.g., a forest with stands only up to age 80 yr, or a forest with stands of only 0-40 yr and 80-120 yr of age). Evenness refers to the balance of representation of stands or edges in each class. For example, a forest of two age classes where one class contains 10% of the area and the other contains 90% is uneven (or, unbalanced). A forest with both age classes containing 50% each would be called even or balanced.

5. Forest Cover Type Diversity

Concept and Rationale

Specific forest cover types, at certain successional stages, fulfill habitat needs for specific categories of wildlife such as marten (McCallum 1993), caribou (OMNR 1989; Antoniak 1993; Cumming and Beange 1993), songbirds (Welsh 1992b), and the barred owl (Van Ael 1993). Timber management in Ontario is changing the forest cover type distribution of the boreal forest (Ontario Forest Audit Committee 1993). Black spruce is becoming less prevalent especially on more productive, better drained sites, and jack pine is being reduced within the mixed softwood cover type. These conifer types are being replaced by mixed wood and hardwood cover types. Tracking of forest cover type distribution can inform one of the extent of forest cover type conversions.

The diversity of forest cover types in a forest is gauged by richness and evenness. The richness of cover types is the variety of cover types. The evenness is the relative amount of area in each cover type. It is especially worthwhile to track naturally occurring cover types which are relatively uncommon in the region or forest, for they are important to the conservation of biodiversity.

Histograms can be prepared for each region, and the FMU forest, to check for spatial anomalies in type-class distribution for each age class. The amount of "old growth", as defined for each type-class, may be particularly useful to track. An example would be black spruce (> 140 years. Conversions of type-classes can also be tracked.

Structure of the Indicator

It will often be useful to re-classify a forest into forest cover types that better characterize habitat types for a given forest region. To track type-class diversity, classify all stands into forest cover types. One is likely to find the forest stand working groups of most forest inventories in Canada too coarse, and the species composition data that define individual stands too fine. A forest stand's working group is the tree species which comprises the majority of the stand, by percent composition of the stand canopy. For naturally occurring types that are of low abundance, one may wish to create special classes for stands that have minor components of the tree species that define the low-abundance types (e.g., special class for other types that contain at least ten percent white pine (*Pinus strobus* L.). A key for working group species and cover types referred to here is presented in Table 8.

For analysis of results, one would prepare an area distribution table for all the cover types (e.g., Table 9), low-abundance types (Table 10), and perhaps also an area histogram for each age class for all types (Table 11).

Data and Analysis Requirements

stand data: age, cover type, including rare types and 10% composition stands
data for entire forest contained in the same data coverage, with regions delineated
coverages: forest

Analysis for Case Study

To track type-class diversity, all stands were classified into forest cover types (Appendix 7 and Table 8). The general strategy was to reduce the classification complexity of stands based on species composition, to a more ecologically meaningful classification. Forest cover types for the Spruce River forest were selected based on what were considered to be relevant ecological types, and by the proportion of the total forest area within a working group. Once stands had been converted to cover types, adjacent stands were aggregated by cover type through a step-wise comparison of every pair of adjacent stands in the forest (Appendix 8). This two-step process created a new forest-cover-type landscape matrix classification.

The richness of area distributions of working groups was examined, and tree species exhibiting relatively low abundance, as evident from FRI data, were identified as requiring special attention. These low-abundance species were identified as: (a) working groups which showed a poor spatial distribution across the regions of the

Table 8: Tree species and cover type key.

TREE SPECIES OR SPECIES CLASS	CODE	COMPOSITION
Conifers	C	all conifers
Hardwoods	Hw	Po, Bw, Ab
Other Conifer	Oc	Ce, La
Spruce	Sp	Sb, Sw
Pine	Pine	Pj, Pw, Pr
Poplar	Po	Pt, Pb
Black Spruce	Sb	
White Spruce	Sw	
Jack Pine	Pj	
White Pine	Pw	
Red Pine	Pr	
Balsam Fir	Bf	
White Birch	Bw	
Cedar	Ce	
Larch	La	
Trembling Aspen	Pt	
Balsam Poplar	Pb	
Black Ash	Ab	

Table 9 : Area of forest cover types within forest regions.

COVER TYPE	FOREST AREA (ha) REGION 1	2	3	4	TOTAL	% OF TOTAL
Sp	19,471.7	65,639.7	57,516.7	38,345.9	180,974.0	28.6
SpC	6,611.0	13,720.4	17,205.1	11,629.8	49,166.3	7.8
SpHW	4,881.2	11,872.9	6,640.4	7,771.9	31,166.4	4.9
SpPi	3,370.3	15,853.9	5,474.1	6,060.6	30,758.9	4.9
Pi	12,735.4	90,501.0	4,147.7	3,795.9	111,180.0	17.6
PiC	52.6	227.0	42.1	209.0	530.7	0.1
PiHW	6,584.8	6,256.6	2,051.1	926.1	15,818.6	2.5
PiSp	6,001.9	16,973.0	8,103.5	6,568.6	37,647.0	5.9
Bf	662.1	1,057.5	2,277.4	2,368.7	6,365.7	1.0
BfC	6,517.9	6,667.0	11,965.6	14,070.1	39,220.6	6.2
BfHW	959.6	2,116.6	4,506.6	8,847.8	16,430.6	2.6
Po	519.1	3,729.8	9,838.1	10,136.7	24,223.7	3.8
PoBw	861.3	1,196.6	1,427.7	570.0	4,055.6	0.6
PoC	9,164.9	9,714.1	15,108.2	16,232.5	50,219.7	7.9
Bw	660.5	1,099.7	486.8	1,557.7	3,804.7	0.6
BwC	4,392.3	6,935.1	7,250.5	4,345.7	22,923.6	3.6
BwPo	302.7	478.9	420.6	403.7	1,605.9	0.3
Ce	90.8	506.0	3,509.2	1,928.4	6,034.4	1.0
La	2.3	193.9	435.8	163.4	795.4	0.1
TOTAL	83,842.4	254,739.7	158,407.2	135,932.5	* 632,921.8	100.0
% OF TOTAL	13.2	40.2	25.0	21.5	100.0	

* productive forest

Table 10 : Presence of low-abundance tree species within other working groups, as area of those working groups, and area of low-abundance working groups, within forest regions.

LA* WORKING GROUP	AREA OF OTHER WORKING GROUPS (ha) REGION 1	2	3	4	LA* WG AREA	GRAND TOTAL	% OF FOREST
Sw	17,214.2	24,206.4	38,655.7	38,130.1	6,988.0	125,194.4	19.8
Pw/Pr	6.3	0.0	29.9	1,042.7	98.0	1,176.9	0.2
Ab	0	0	49	463.6	0	512.0	0.08
TOTAL AREA OF REGION	83,842.4	254,739.7	158,407.2	135,932.5	NA	632,921.8	100

* LA = low-abundance

Table 11: Age class distribution for forest species working groups for the Spruce River forest.

WORKING GROUP	AREA (ha)							
	AGE CLASS							
	<1	1-20	21-40	41-60	61-80	81-100	101-120	>120
Sb	57,831.8	29,307.1	6,550.8	33,923.4	70,451.8	50,380.7	28,310.1	8,228.0
Pw	0.0	0.0	0.0	0.0	0.0	0.0	58.2	9.6
Pj	12,851.0	83,590.2	2,617.2	29,603.6	28,235.8	5,571.2	1,804.5	839.4
Sw	824.4	1,441.6	64.2	1,057.0	2,688.6	774.1	204.9	0.0
Bf	3,536.1	1,223.9	21,791.0	31,824.4	3,369.8	242.0	6.6	0.0
Po	13,693.9	2,723.9	2,114.6	19,383.5	28,942.9	10,474.0	1,034.3	124.7
Bw	2,617.2	552.4	3,837.6	12,000.3	5,911.1	2,602.4	607.7	196.7
Ce	654.8	23.2	14.6	31.9	537.0	2,008.7	1,863.4	901.1
La	48.5	0.0	0.0	81.0	341.5	135.6	133.6	55.2
FOREST TOTAL	92,057.7	118,862.3	36,990.0	127,905.1	140,478.5	72,188.7	34,023.3	10,354.7

forest, (b) a low presence in the forest as a working group, or (c) appeared to be at risk of reduction in extent, or elimination from the FMU.

Results were tabulated for area distribution for all cover types, and displayed as histograms for comparative analysis. The presence of low-abundance species was measured by tabulating their presence as a component within stands of all working groups, in addition to the area of the low-abundance species' working groups themselves.

Results

The two major working groups by area in the Spruce River forest are Sp (*Picea sp.*) and Pi (*Pinus sp.*), followed in descending order by Po (*Populus sp.*), Bf (*Abies balsamea* L. Mill.), and Bw (*Betula papyrifera* Marsh.) (Table 9 and Figure 5). The major cover types are Sp and Pi. The forest area of 633,000 ha reported for both the cover type diversity and age class diversity indicators refers to productive forest area. Pine occurs predominantly in the pure cover type (18% of the forest), with the next largest pine cover type being PiSp (6% of the forest). The four spruce cover types make up 46% of the 633,000 ha area of the forest. The SpC, SpHw, and SpPi types each cover at least 5% of the forest. Other major types that contribute at least 5% of the forest area are BfC (6%), and PoC (8%). PiHw, BfHw, Po, and BwC types each cover between 2.5% and 5% of forest area. The predominant poplar and birch cover types are mixedwood (BwC and PoC). Minor cover types that are 1% or less of the forest area, in descending order, are: Bf, Ce (*Thuja occidentalis* L.), PoBw, Bw, BwPo, PiC, and L (*Larix laricina* (Du Roi) K. Koch).

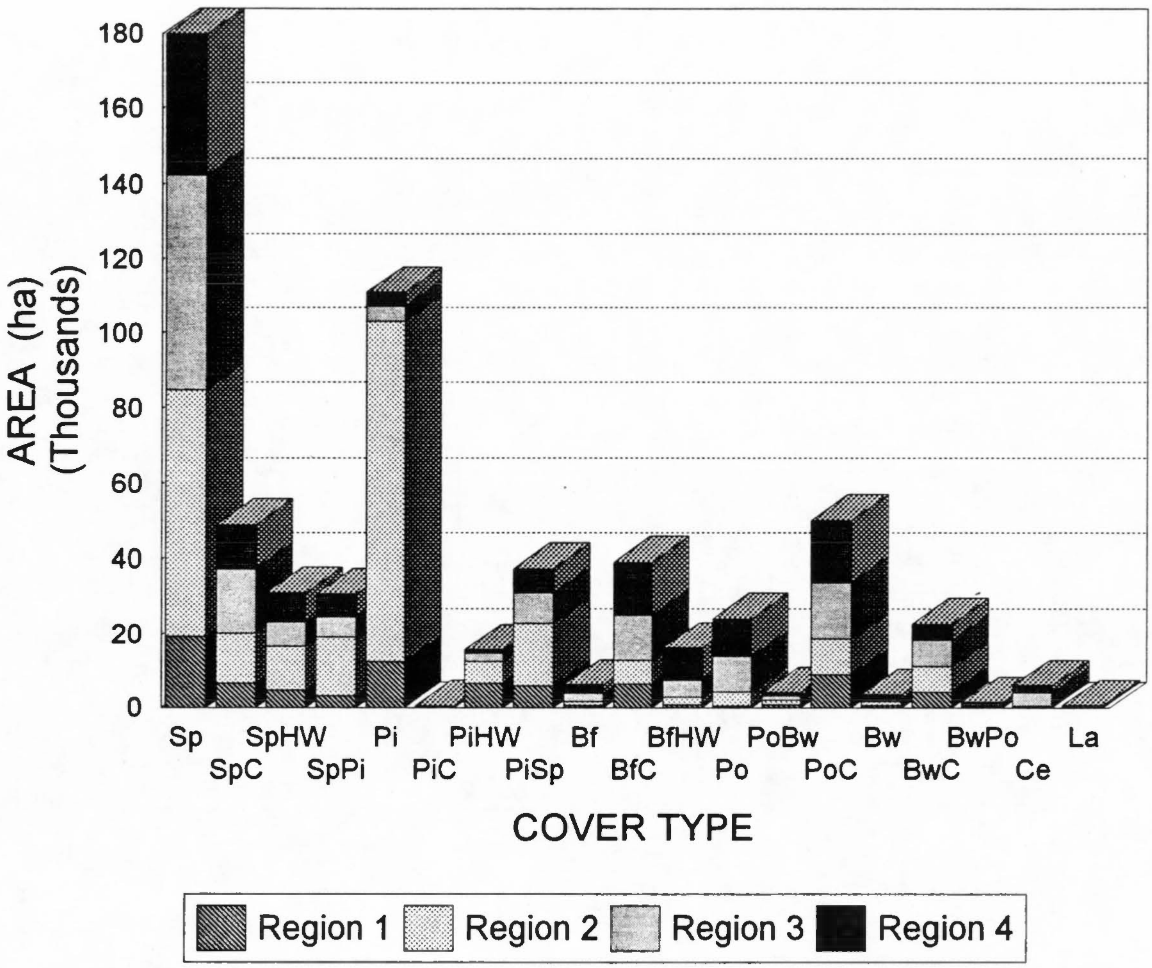


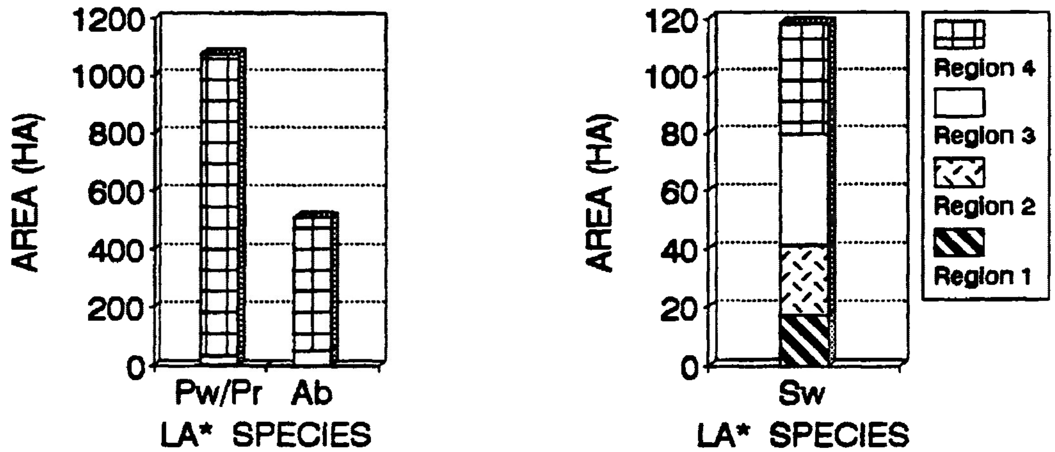
Figure 5 : Forest cover type distribution by area, for forest regions, for the Spruce River forest.

Among the designated low-abundance tree species within the forest, the combined presence and working group percent area is 20% for Sw (*Pices glauca* (Moench) Voss), 0.2% for Pw/Pr (*Pinus resinosa* Ait.), and 0.08% for Ab (*Fraxinus nigra* Marsh.) (Table 10 and Figure 6).

The spruce cover types are distributed quite evenly over the four regions of the forest (Table 9 and Figure 5). SpC occurs proportionally less (that is, as a proportion of regional area) in region 2 than in other regions, while SpPi is proportionally greater in region 2. The pine cover types cover proportionally more of regions 1 and 2 than the southern regions, except for PiSp which is more evenly distributed across all regions. There is a relatively significant proportion of PiHw in region 1 of 6,580 ha, and it occurs in regions 2 and 3 to a lesser extent.

In regions 3 and 4 the balsam fir types are proportionally much greater than in the northern regions, except for significant area of BfC in region 1 of 6,520 ha. Within the poplar types, there is significant area of PoC that occurs in the three southern regions, and Po occurs predominantly in regions 3 and 4 in the south as well. The dominant birch type, BwC, is fairly evenly distributed throughout the forest, with a lower proportion occurring in the northern region. The vast majority of Ce occurs in the southern two regions. Region 3 holds the majority of the 790 ha of La in the forest.

Within the designated low-abundance types, Sw occurs in other working groups significantly throughout the forest, and to a proportionally greater extent in region 1 (17,210 ha), and to a lesser extent in the northern region (24,210 ha) (Table 10 and Figure 6). Pw/Pr and Ab have similar distribution patterns, occurring mostly in the



* LA = low-abundance

Figure 6: Presence of low-abundance tree species within other working groups, as area of those working groups, for the Spruce River forest.

southern region, and being extremely restricted in area in region 3. There is also a trace (6.3 ha) of Pw/Pr in region 1.

Interpretation and Evaluation

The Spruce River forest has a relatively high richness of cover types for the boreal region. This is due to the occurrence of several cover types within the major working groups, and the presence of Sw, Pw/Pr, and Ab. There is a low to medium evenness in the amount of area in these cover types. The forest area distribution is dominated by two major types; there is a second group of ten types that are somewhat even in type diversity, and a third group of types with very low areas, including the low-abundance types. The species richness of the four regions of the forest are virtually the same, except for the absense of Pw/Pr in region 2, and the lack of Ab in both northern regions.

The evenness of the area distribution varies for most cover types among regions, except for spruce and birch types. Most of the pine types are more dominant in the two northern regions than in the south, while fir, poplar, cedar, and larch types are more dominant in the two southern regions.

The richness and evenness of cover type diversity for this forest would be gauged for sustainability based on comparison to historic values for this region of the boreal forest. Since the forest has had a logging presence for only some 40 years, it may be possible to determine historical patterns. Any types that were determined to be reduced in extent over time in a regional context, and the low-abundance types, may be targeted to be maintained or enhanced due to their important contribution to species richness. The accuracy of this indicator may have been reduced by the integrity of forest regeneration data. For instance, the area of Sp and Pi cover types may be unrealistically large since unknown regenerating stands in those working groups were designated as pure stands.

6. Forest Age Diversity

Concept and Rationale

Most boreal-forest stands have an evenaged overstory in which all the trees have their origin together at the time of a major disturbance. The determination of stand ages across large forest areas is fraught with uncertainty and requires much professional judgement. Nonetheless, boreal stands are given an age in many forest inventories. The distribution of forest area among all possible stand age classes, given that age is a reasonable proxy for many stand characteristics, can be an important integrative indicator of overall forest condition. Two examples of the importance of age-class distribution are: (a) some wildlife species strongly prefer specific age classes (or rather, stand conditions as represented by age class, e.g., marten and caribou for older coniferous stands); and (b) unbalanced age-class structures present special problems to managing a boreal forest for timber, e.g. low amounts of stand area in younger age classes may curb timber availability several decades in the future.

It may be important, as one considers forest naturalness, to compare a boreal forest's potential natural age-class structure with that created under management treatments such as clearcut harvesting and fire suppression. The decline in incidence of fire due to fire suppression has meant the "alteration and reduction of the major vector of natural development of boreal succession patterns" (Thompson 1992). Forest clearcutting can, if deliberately designed for this purpose, create a fire-like pattern of successional patches across the landscape. The fire-origin disturbance regime of the boreal forest created a landscape consisting of a large range of forest patch sizes. Large disturbance patches cover the majority of the landscape, and generally all the ecosystems within a disturbance patch are the same age (Welsh 1992b).

The richness and evenness of forest-stand age-class distributions give a picture of the diversity of stand ages within the forest. Histograms are especially useful for illuminating anomalies in forest age-class distribution.

Structure of the Indicator

To track age-class diversity, classify all stands of each forest type (say, working group) into age classes (say, 20-yr classes) (see Table 11), and prepare an area histogram for all age classes in each type. Special consideration might be given to all the forest types containing some proportion of less common tree species (e.g., white pine).

Data and Analysis Requirements

stand age, cover type, including low-abundance types and 10% composition stands
entire forest contained in the same coverage, with regions delineated
coverages: forest

Analysis for Case Study

The distribution of forest area by age class was determined for each forest species working group (Table 11) and forest cover type (Table 12). Age distribution histograms were created, including low-abundance types, for comparison between working groups and cover types.

Results

There is generally high richness in age distribution for all working groups (Table 11 and Figures 7-11) with the exceptions of Sw and Bf which are not represented in the > 120 year age class, La which is not represented in the 1-40 year range, and Pw which is only represented above 101 years.

All cover types exhibit some form of a bell-shaped distribution and low evenness in age classes (Table 12, Figures 10 and 11). All cover types except Bf and Bw have a deficiency of area in the 21-40 year class (Figure 8). The 41-60 year age class contains significant area of all major cover types, especially BfC, PoC, Sp, and PiSp. Spruce, pine, and poplar have large spikes in their area distributions in very young ages within their pure cover types. Pi dominates the 1-20 year age class (Figure 7) due to Pj (*Pinus banksiana* Lamb.) regeneration of old vast burn of 89,000 ha in the northern region. The older age classes of the forest (> 80 years) are dominated by the spruce types (Figure 9). Ce and La have characteristic age distributions that are skewed to the mature and old ages (> 60 years).

Table 12: Age class distribution for forest cover types for the Spruce River forest.

COVER TYPE	AREA (ha) AGE CLASS (years)							
	< 1	1-20	21-40	41-60	61-80	81-100	101-120	> 120
Bf	797	5	2,982	2,357	186	25	7	0
BfC	2,170	1,061	11,906	21,483	2,391	203	0	0
BfHw	570	158	6,903	7,984	793	14	0	0
Bw	1,605	186	203	1,328	77	213	189	3
BwC	840	259	3,585	9,864	5,661	2,191	419	98
BwPo	172	108	49	809	174	199	0	96
Ce	655	23	15	32	537	2,009	1,863	901
L	49	0	0	81	342	136	134	55
Pi	10,953	78,286	1,169	9,845	9,470	1,104	319	44
PiC	37	98	97	140	147	13	0	0
PiHw	970	871	474	7,171	5,665	613	22	31
PiSp	892	4,335	877	12,447	12,955	3,841	1,522	775
Po	11,610	824	186	2,370	6,409	2,756	67	0
PoBw	34	276	108	2,022	1,046	389	160	20
PoC	2,050	1,624	1,820	14,991	21,488	7,329	807	105
Sp	52,797	24,779	2,624	14,907	30,415	27,865	19,938	7,632
SpC	3,731	1,031	2,159	8,671	20,304	8,607	4,246	418
SpHw	1,238	1,490	1,183	6,248	11,649	7,544	1,769	43
SpPi	890	3,449	649	5,154	10,774	7,139	2,563	136
FOREST TOTAL	91,261	118,857	34,008	125,548	140,292	72,164	34,017	10,355
% OF TOTAL	14.4	18.8	5.4	19.8	22.2	11.4	5.4	1.6

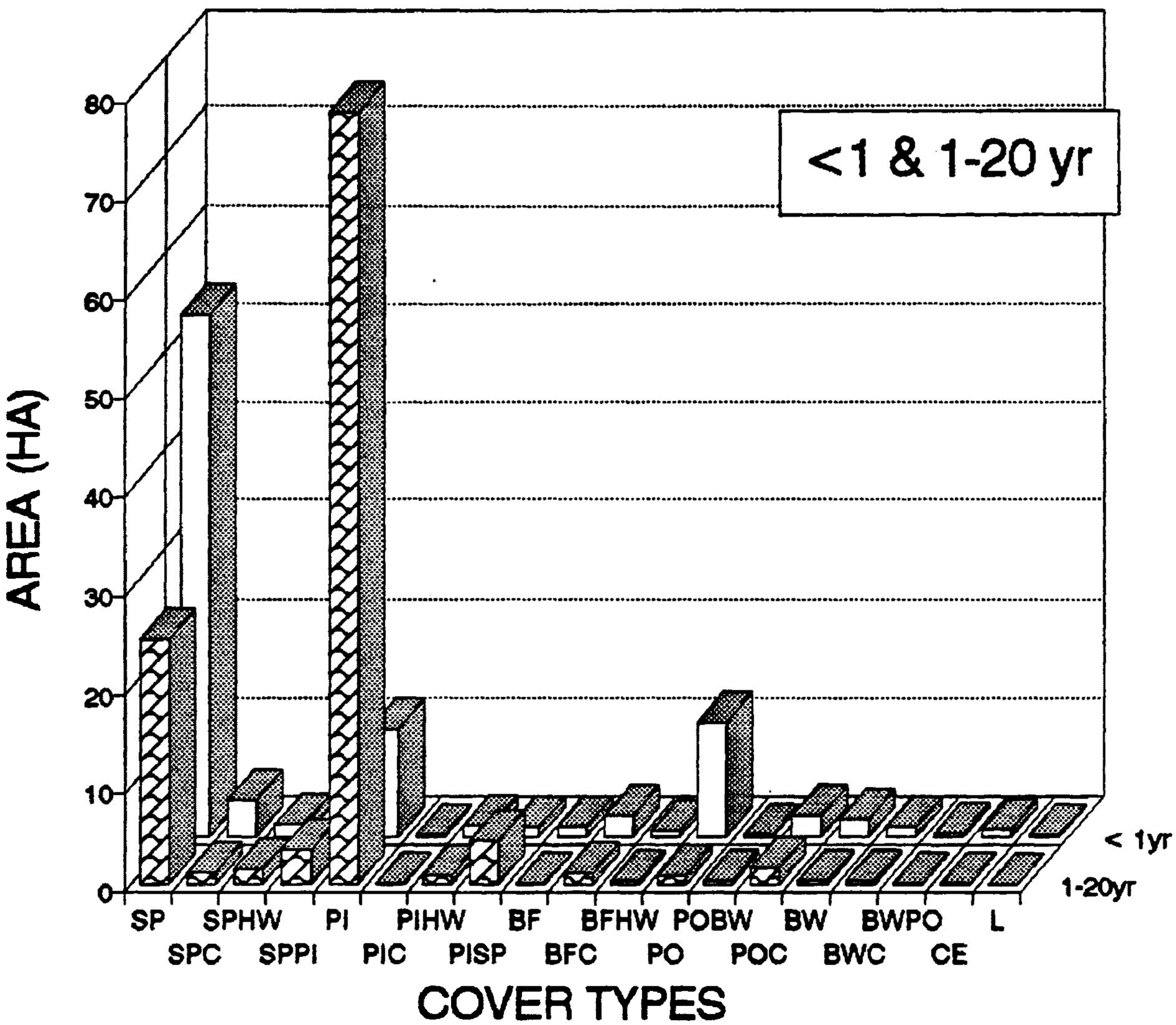


Figure 7: Forest cover type distributions for age classes < 1 and 1 - 20 years for the Spruce River forest.

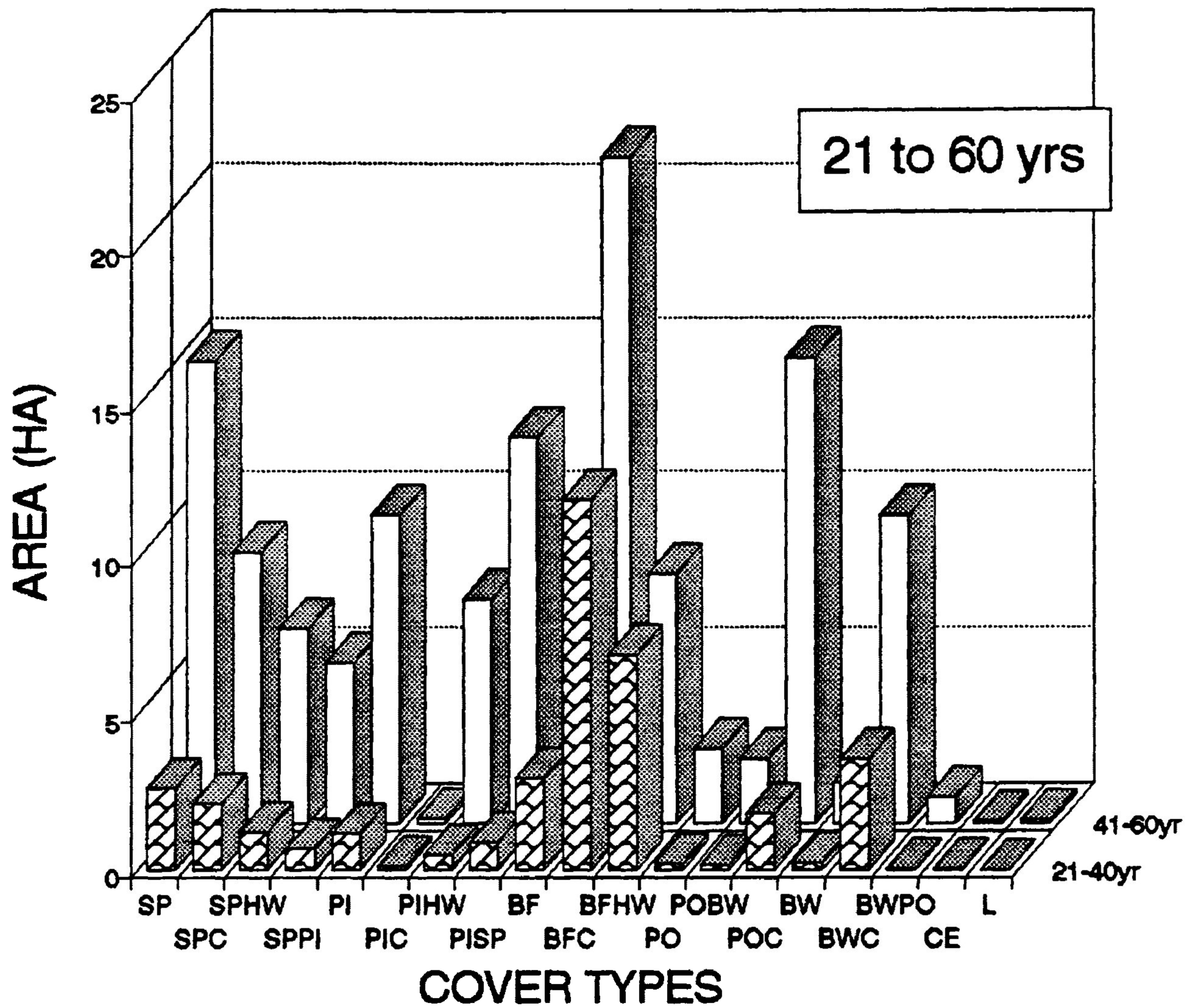


Figure 8 : Forest cover type distributions for age classes 21 - 40 and 41 - 60 years, for the Spruce River forest.

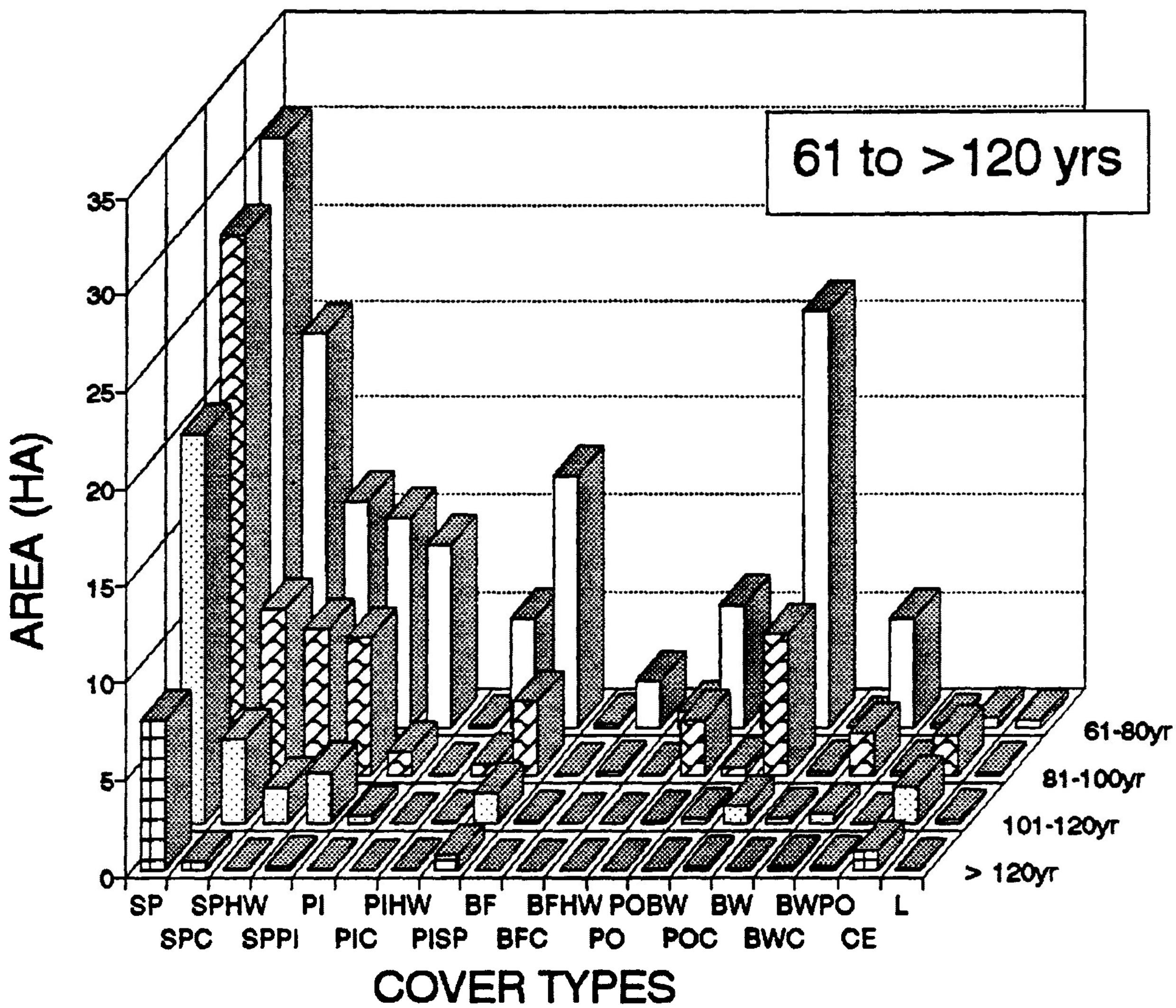


Figure 9 : Forest cover type distributions for age classes 61 through > 120 years, for the Spruce River forest.

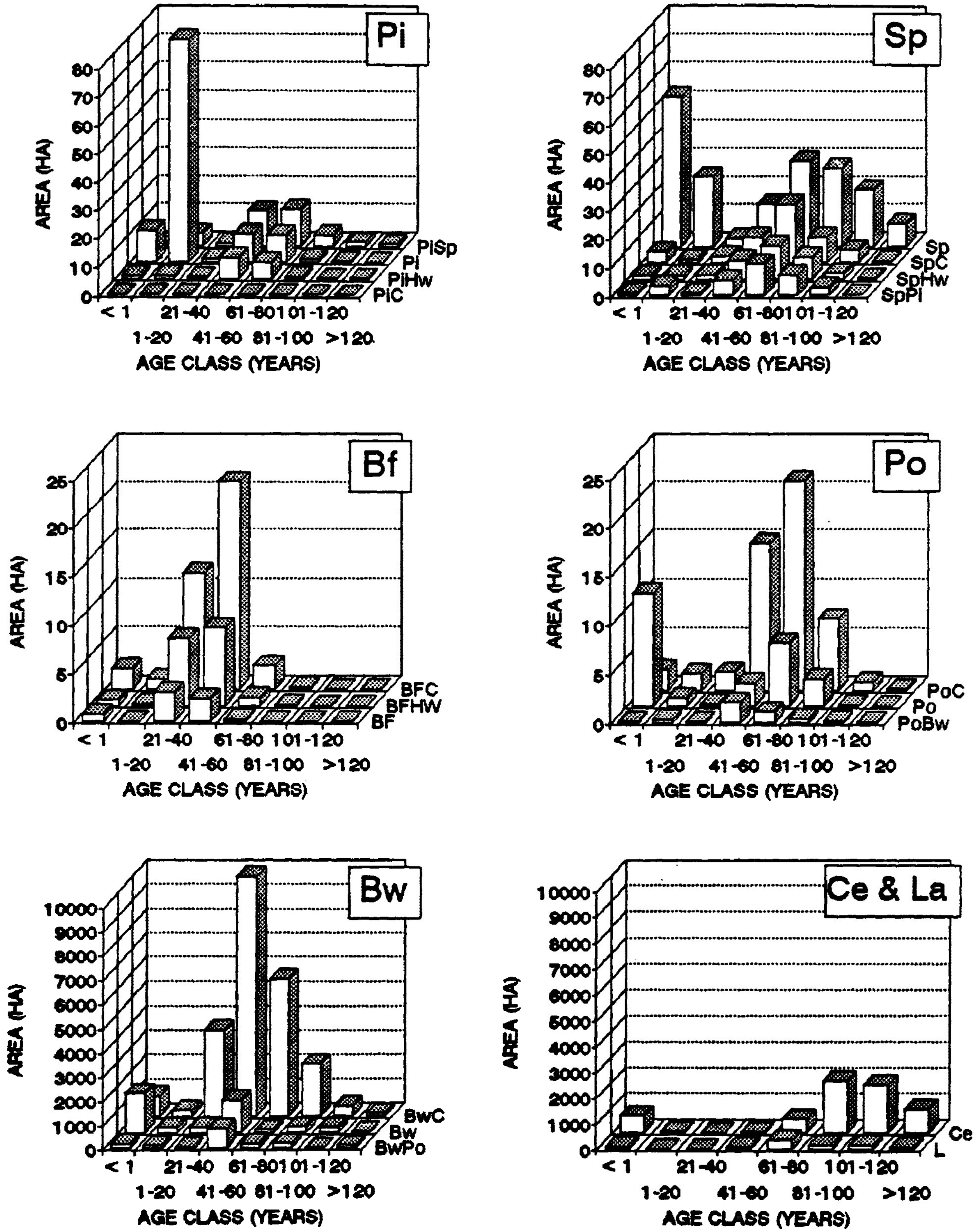


Figure 10: Age class distribution for forest cover types for the Spruce River forest.

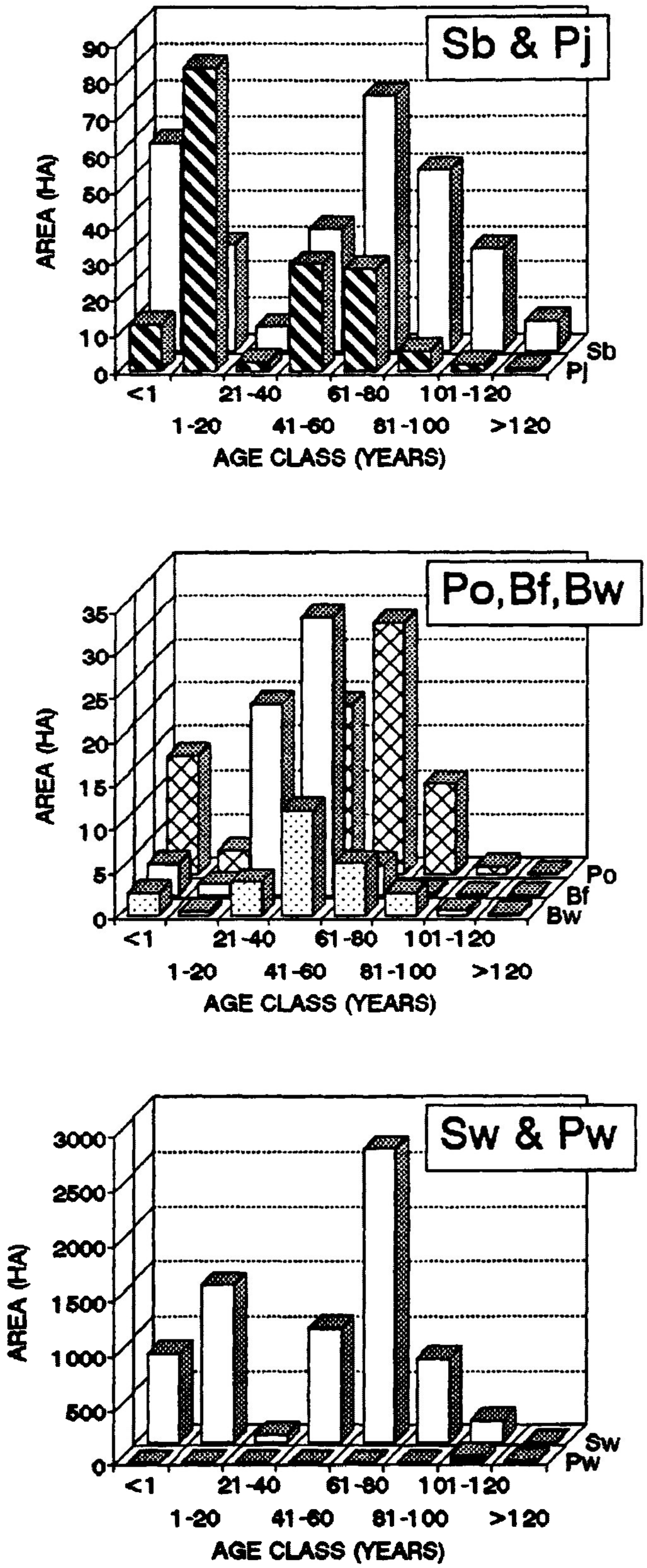


Figure 11: Age class distribution for species working groups, including low-abundance types, for the Spruce River forest.

Interpretation and Evaluation

The desired levels for richness and evenness for forest age diversity would be partially based on the phytosociological characteristics of the different species for this region of the boreal forest. As well, the typical age class distribution of boreal forest within this climatic zone would serve as a comparative baseline. The regional forest age class diversity of neighbouring FMU's could also provide a guide for this forest. The general under-representation in the 21-40 year age class in the forest means a low supply of habitat for species requiring habitat characteristic of that age class, both now and in the future when it enters mature, then old age classes. There also will be a shortage of mature pine habitats in the future, if there are high logging levels of pine types, because the majority of the area of pine cover types is concentrated in young age classes (< 21 years). There appears to be a sufficient amount of spruce types in mature and old classes, up to 100 years, to ensure the supply of those habitats into the future.

The low representation in young and mature classes for Ce is not a concern since it is a sub-climax to climax species (Sims et al. 1990). There is a concern with La since it is a pioneer species (Sims et al. 1990) and may disappear without regeneration. White pine as a working group exists at extremely low levels, and occurs only in the old age classes. Silvicultural efforts to regenerate white pine would improve its age diversity, as well as maintain its presence in the forest.

As stated previously under "Type Diversity", this indicator may also have reduced accuracy due to poor inventory data. The young regenerating age classes are likely over-represented in the pure types for Sp, Pi, and Po. However, the amount of

Pi working group in the 1-20 age class may have been under-estimated due to the method used to assign missing data to the burn (see Appendix 6), since stand conversion to Pj is likely to occur where Pj was present as a significant sub-component in a stand that has burned.

7. Fragmentation - Forest Patch Size and Configuration Diversity

Concept and Rationale

According to Harris and Silva-Lopez (1992), fragmentation is the unnatural detaching or separation of expansive tracts into spatially segregated small patches. DeGraaf and Healey (1988) interpreted forest fragmentation as a process whereby sections of forest overstory are removed on a temporary or permanent basis. In the boreal forest, fragmentation occurs as a result of management treatments (e.g., clearcutting) and of natural disturbances (e.g., windthrow, wildfire). Fragmentation of large tracts of forest produces conditions of increased open habitats, and island effect, which do not fulfill the habitat needs for interior-, area-, and human-sensitive forest wildlife (Harris 1984; Thompson 1988). Habitat fragmentation is considered to be "the single most significant challenge ... to the survival of wildlife altogether" (Temple and Wilcox 1986). The complex consequences of fragmentation within a matrix of agricultural land have been thoroughly reviewed elsewhere (Saunders et al. 1991).

Fire is the predominant factor producing natural landscape patterns across the boreal forest (Heinselman 1981; Ward and Tithecott 1993). The pattern of fire frequency across northern Ontario grades from high frequencies at the Manitoba border to low frequencies in the northeast (Suffling 1991). The impact of human fire suppression depends upon the natural fire-return frequency for a given area. In regions of naturally high fire return, the combined effects of fire suppression and timber cutting have created a new and artificial pattern across the boreal forest landscape of Ontario.

Timber management can affect the boreal landscape mosaic in a number of ways (Middleton 1991). Conventional clearcutting in the boreal forest has reduced the average patch size and distribution (Thompson 1992; Ward and Tithecott 1993). Timber management based on moose habitat guidelines benefits species that use edge habitat and early successional stages (Middleton 1991). The pattern and size of cuts determine the size and distribution of future habitat patches, and the size and configuration of the forest matrix remaining on the landscape. The size, number, and complexity of habitat patches is correlated with the total amount of edge, and forest interior habitat. A forest region that consists of a patch pattern which is extremely convoluted, and contains a high number and small size of patches, possesses a relatively large total amount of edge. On the whole, the patterns of clearcut timber harvesting and fire suppression in Northern Ontario over the past 50 years have changed forest biodiversity away from natural patterns.

Structure of the Indicator

To track the size diversity of stands (or cover types, or forest patches) in a forest, classify all stands of each type into 10 to 20 ha size classes. Observe stand size distribution, and set aggregate size classes appropriate for analysis. Prepare area and number histograms for all aggregate size classes in each forest type (see Figures 12 and 13). Maps for different landscape classifications, of forest cover type and a redefined forest patchwork, can illuminate landscape patterns and complexity.

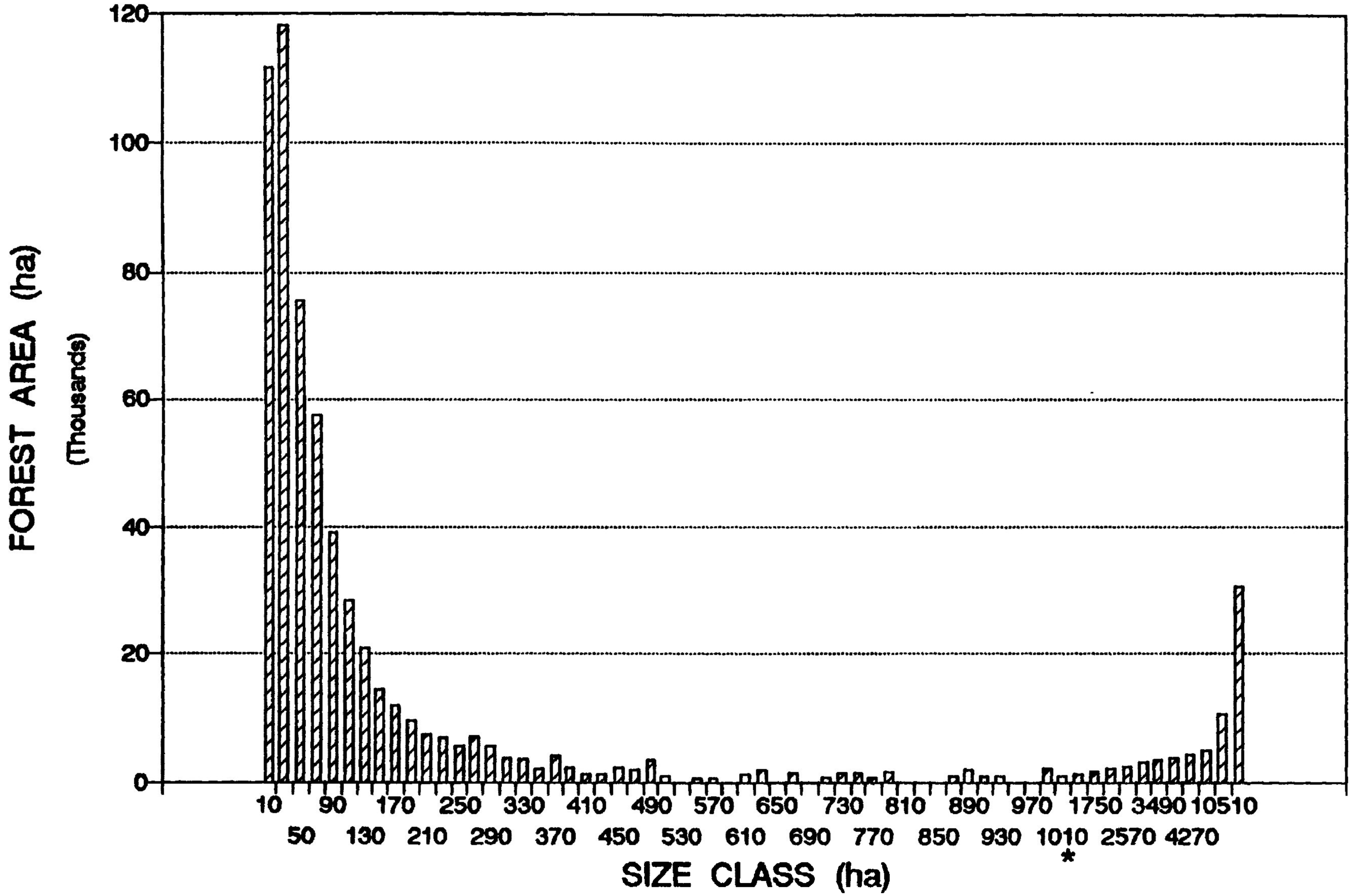
Data and Analysis Requirements

stand data: age, cover type (including low-abundance types with 10% stand composition)
data for entire forest contained in the same data coverage, with regions delineated
coverages: forest, roads, edge (height, stocking, roads)

Analysis for Case Study

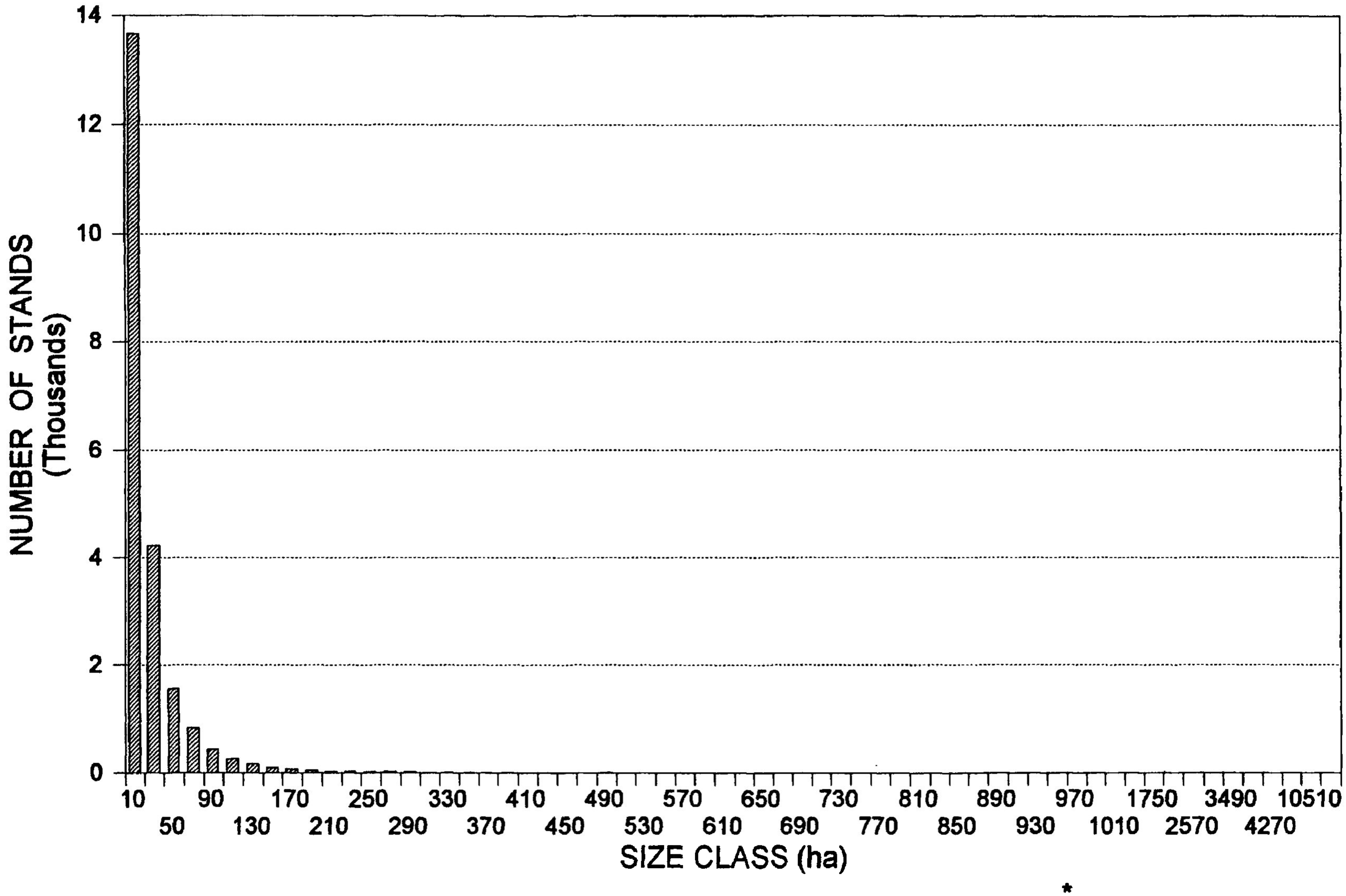
A size-class distribution was created for the entire Spruce River Forest FMU, under the FRI classification (Appendix 3.1). Histograms were produced for the distribution for forest area and cumulative percent area (Figures 12 and 14), and a pie chart for forest area (Figure 15). A stand size-class distribution of the number of stands was also charted (Figures 13 and 16).

A new forest classification was created for region 3 based on criteria for the two forest edge types of height and stocking, in addition to roads (Figure 17). A size class distribution was then produced for this forest landscape patchwork (Appendix 3.2). Distributions for area and patch number were plotted (Figures 18 and 19).



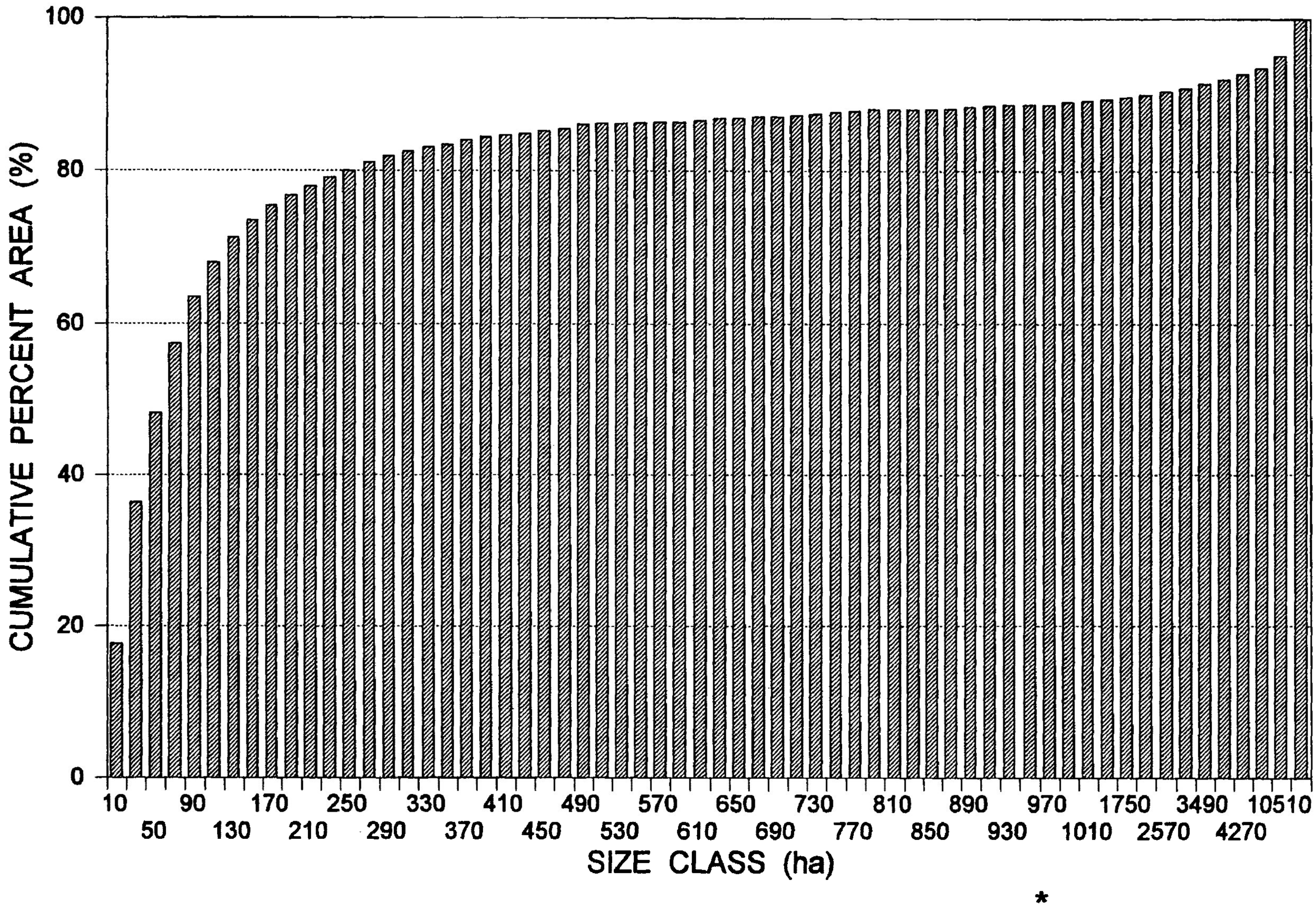
* Above 1010 ha, size classes are not sequential

Figure 12: Stand size class distribution for stand area for the Spruce River forest.



* Above 1010 ha, size classes are not sequential.

Figure 13 : Stand size class distribution for stand number for the Spruce River forest.



* Above 1010 ha, size classes are not sequential.

Figure 14 : Stand size class distribution for cumulative percent area for the Spruce River forest.

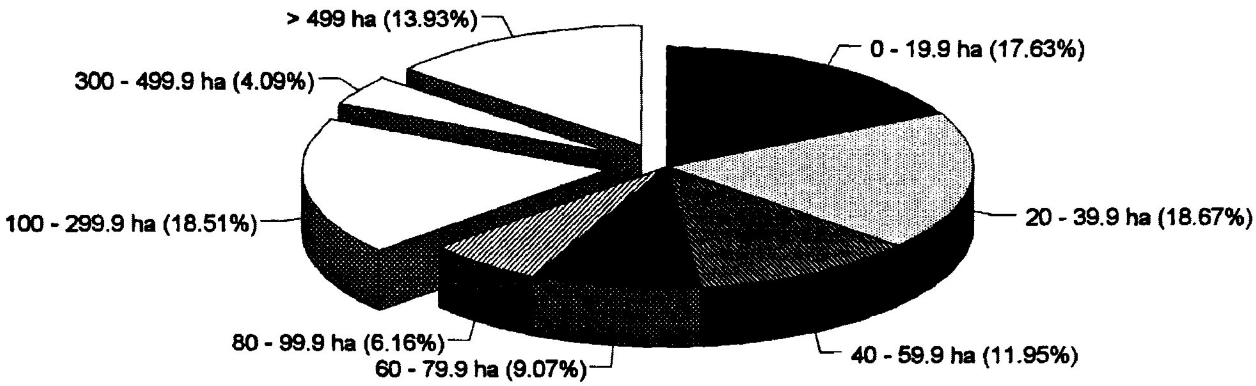


Figure 15 : Stand size class pie distribution for stand area for the Spruce River forest.

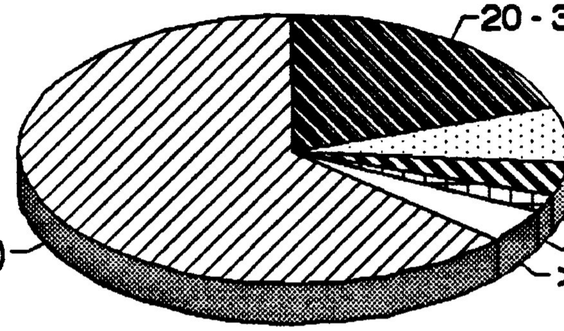


Figure 16 : Stand size class pie distribution for stand number for the Spruce River forest.

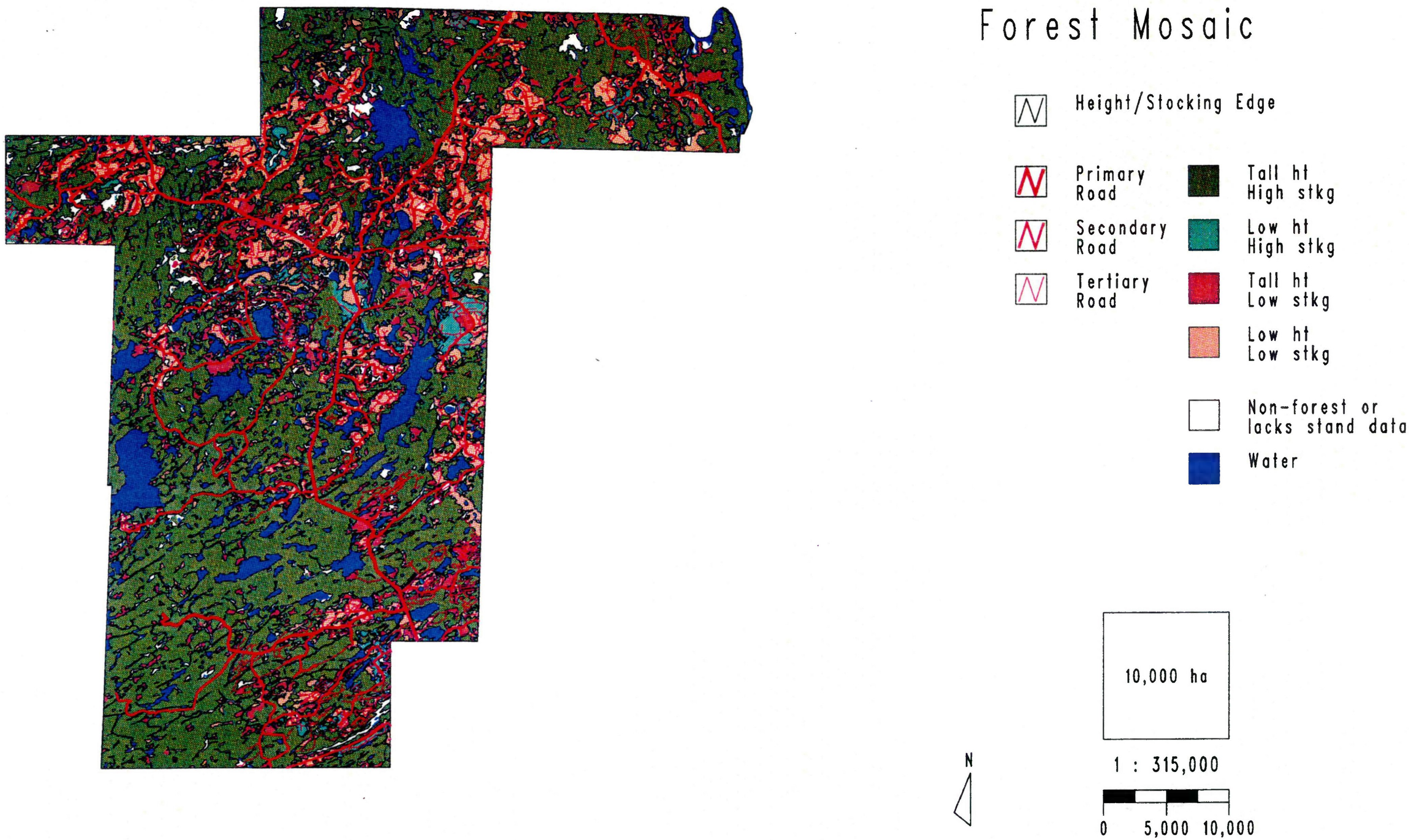
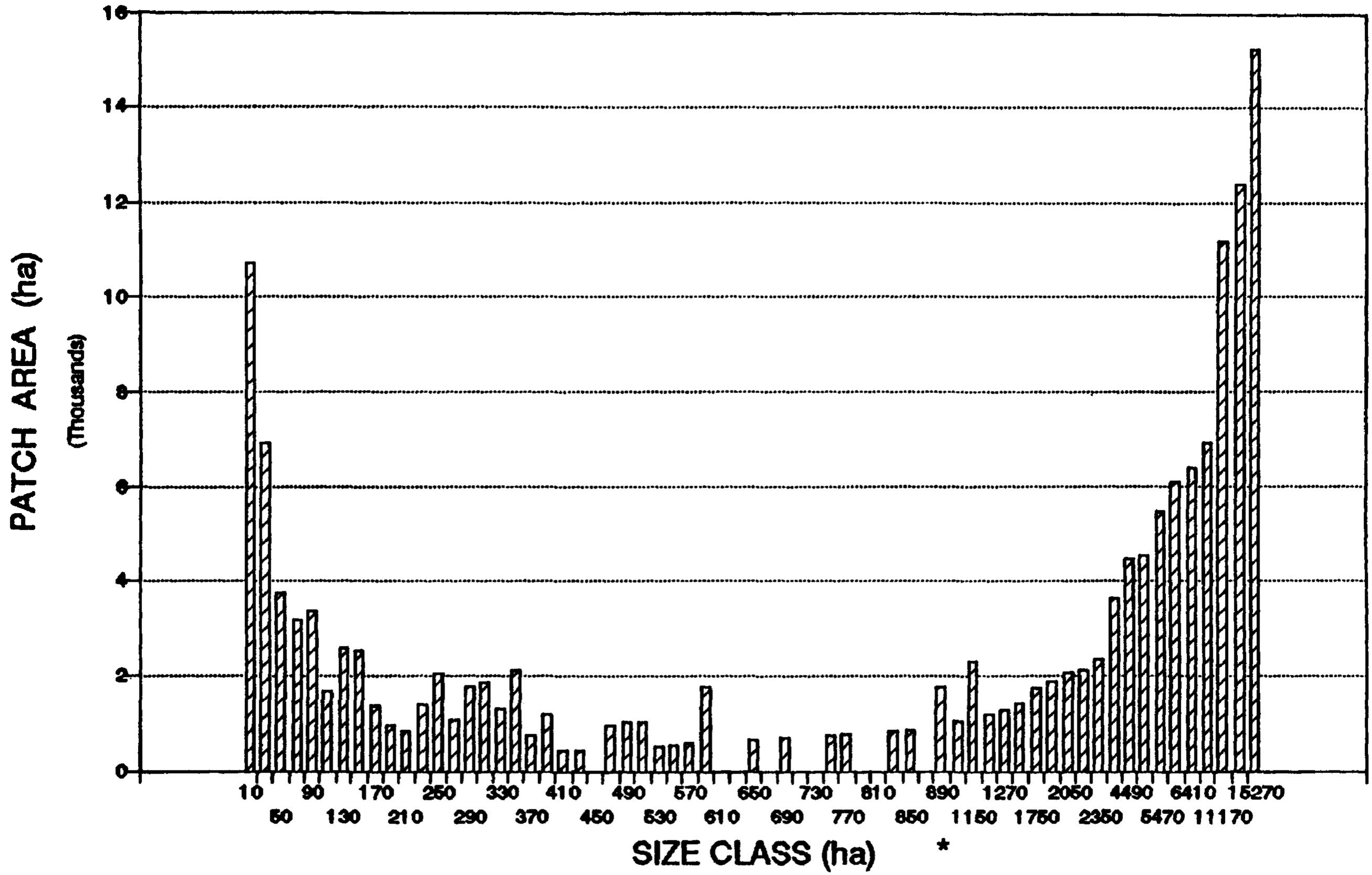
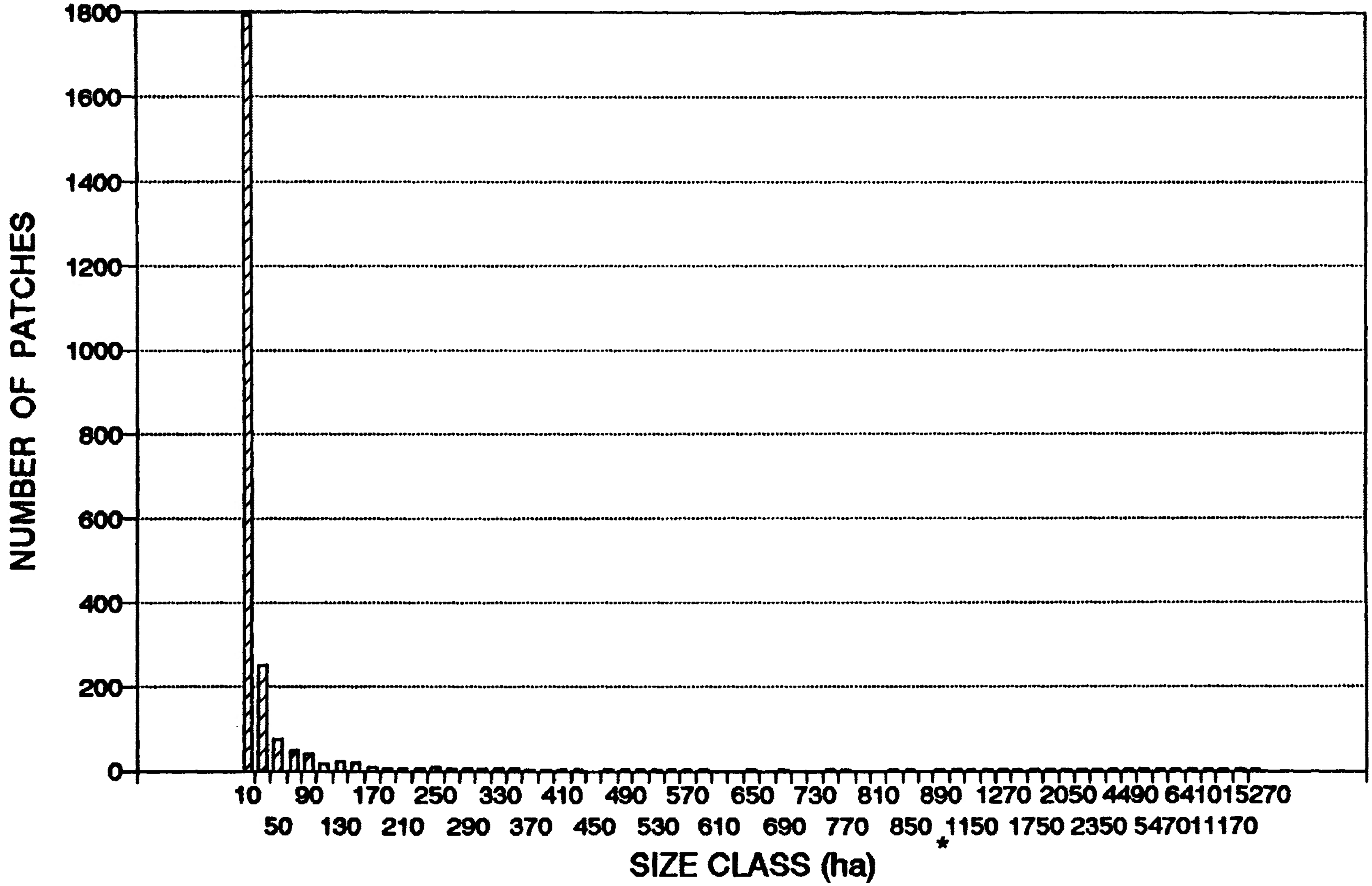


Figure 17: Forest mosaic of the Spruce River forest formed by the combination of height and stocking edges, and primary and secondary roads.



* Above 890 ha, size classes are not sequential.

Figure 18 : Patch size class distribution for forest patch area, for region 3 of the Spruce River forest.



* Above 890 ha, size classes are not sequential.

Figure 19 : Patch size class distribution for forest patch number, for region 3 of the Spruce River forest.

Results

The stand size-class distribution for area for the entire Spruce River Forest, under the FRI classification, follows a general pattern of a negative exponential curve except for anomolies in the extremely large stand classes (Figure 12). Stands occur in all size classes up to 510 ha, and in most size classes up to 1,010 ha. Above 1,010 ha there are nine stands scattered amongst classes up to 5,000 ha, one stand in the 10,500 ha class, and one stand in the 30,510 ha class. 36.3% of forest area is in stands below 40 ha, 64% is under 100 ha, and 14% is in stands > 500 ha (Figures 13 and 14). With regard to the number of stands, 63% of stands are below 20 ha in size, and 4% of stands are > 100 ha (Figures 15 and 16).

The new classification for region 3 portrays a fairly continuous forest cover in the southwest of the region, interrupted only by lakes, non-commercial forest, non-forest, and roads (Figure 17). Much of the northern part of the region is undergoing fragmentation by logging, which is closely associated with the road system. For region 3, the patch size-class distribution for area below 10,000 ha bears some resemblance to a negative exponential distribution (Figure 18). In contrast to the distribution for area for the FMU (Figure 12), within the patch size-class distribution for area for region 3, the majority of the forest area is skewed to the large patch size classes > 1,000 ha. As well, the area is more evenly distributed across the mid-size patch range. The size-class distribution for number of patches (Figure 19) drops rapidly from 1,792 stands in the 10 ha class to very low levels by the 170 ha class.

Interpretation and Evaluation

To determine targets for the forest patch-size diversity of the FMU or each region, the present distributions for the forest could be compared to size-class distributions for area and number for stands or patches of representative natural landscapes. This comparison could be applied to the geographic distribution of patches as well.

The distribution for stand area for the FMU may be over-representing area in the small stand size range due to the nature of FRI classification which delineates individual stands from the forest cover for timber-management purposes. Alternatively, the distribution for area for region 3 may provide a more ecologically realistic forest-patch size distribution since it is based on patches of forest height and stocking in addition to roads. However, this distribution may be over-represented in the large patch size class range due to some narrow inter-connections between stands in the forest which may artificially enlarge the ecologically effective size of some patches.

This indicator in particular demonstrates the value of utilizing more tailored classifications of the forest other than FRI to picture the forest as a landscape, so it can be managed as a landscape. Other classifications of the forest are possible, depending upon the ecological criteria of interest.

8. Old-Growth Forest Patch Size and Configuration Diversity

Concept and Rationale

Old-growth is defined as ecosystems that are "...relatively old, and relatively undisturbed by humans" (Hunter 1989). This definition has been adopted by the Ontario Old Growth Policy Advisory Committee (OGPAC 1993)). The concept of old-growth can be applied to all forest cover types (Jeglum 1991). The multiplicity of values dependent upon old-growth include: existence, spiritual, knowledge, natural heritage, aesthetic, therapeutic, character-building, ecological functioning, wilderness recreation, subsistence use, and market fur and timber values (Rolston 1987; Payne 1990; OGPAC 1993).

Old-growth wildlife and its habitat are of special interest within existence-type values since they are critical features of the forest that people want to be assured are fulfilling, and will continue to fulfill, their ecological role (OGPAC 1993). Boreal old-growth, particularly that dominated by conifers, is crucial habitat for interior forest wildlife. Marten are known to prefer old-growth conifer habitat (Thompson 1991). Many songbirds, including the Bay-breasted warbler and the ovenbird for example, depend upon middle to late forest successional stages (Welsh 1988).

Habitat requirements of size, shape, proximity, and spatial arrangement of natural forest types are only partially known for a few species (Temple and Wilcox 1986). In Ontario there is little quantitative knowledge of the habitat patch-size requirements of important interior, old-growth forest species such as cavity nesters, passerine birds, some small mammals, and especially invertebrates (Welsh et al.

1992).

Some boreal forest fauna are known to be negatively affected by logging mature and overmature stands. Caribou populations are threatened by fragmentation of conifer old-growth and the subsequent increase in predator populations (OMNR 1989). The distribution of caribou has receded northwards in northern Ontario, and caribou populations have been reduced due to timber management activities (Darby and Duquette 1986; OMNR 1989; OMNR 1990; Antoniak 1993; Cumming and Beange 1993). Logging boreal old-growth has a negative effect on at least two furbearers in Ontario: ermine and marten (Thompson 1988).

It is a common priority in management of Ontario's boreal forests to harvest old forests first. This represents a threat to the species that depend upon old-growth habitat (Cundiff 1990). Moreover, the traditional dispersed pattern of cutting brings about unnatural size distributions and complexity of forest cover types (Franklin and Forman 1987) that disrupt old-growth values, particularly old-growth wildlife populations.

Key features of old-growth forest are its patch size and patch configuration diversity. The greater the old-growth fragmentation, the less its value as habitat for wildlife requiring old-growth interior forest. Effective area of old-growth is the extent of old-growth forest which, from a wildlife perspective, is unfragmented, and does not present insurmountable barriers to wildlife in using the entire old-growth area. A larger effective area of old-growth exists if the distance between old-growth patches is smaller than a critical level, beyond which given wildlife species will not move from one patch to another. A contiguous old-growth patch refers to an expanse of old-growth forest that is completely inter-connected, that provides for free movement of wildlife throughout the patch area. Larger contiguous old-growth patches, with less complexity, favour interior forest wildlife.

Structure of the Indicator

Specific age classes of forest cover are tracked to determine the present and potential future distribution of forest ecosystem with old-growth characteristics. The forest can be classified crudely (e.g., coniferous and hardwood, Table 13) or using more-detailed types. For each cover-type class, precise ages need to be specified for stands to be considered old-growth. It may be helpful to use the following two classes: (a) mature stands (i.e., closed-canopy stands where tree growth is relatively steady; and (b) old or old-growth stands (i.e., where tree growth is declining, and dead and down wood is increasing).

Tracking areas in old-growth age classes would simply be a special case of age-class structure analysis (see Table 14). More important is to track old-growth fragmentation, where all old-growth stands are analyzed for size and complexity, as described earlier. Maps, at regional and forest scales, are integral to gauging old-growth fragmentation.

Data and Analysis Requirements

data format: vector
data for entire forest contained in the same data coverage
coverages: roads, forest

Table 13: Old-growth cover type definitions.

	Forest Cover Composition		
	Cover Type		
	Softwood	Hardwood	Mixed Wood
Definition:	SW ≥ 80%	HW ≥ 80%	SW & HW = 30%* to 70%

* 40% to 70% cover composition for interior old-growth cover type

Table 14: Area of > 40% conifer, old-growth and potential old-growth (mature) forest combined, and interior forest, for the Spruce River forest.

FOREST REGION	AREA	CONIFER AREA *		INTERIOR CONIFER AREA *		EDGE FOREST AREA		OTHER FOREST AREA	
	(ha)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
1	83,842	56,981	68.0	51,913	61.9	5,068	6.0	26,861	32.0
2	254,739	105,529	41.4	92,449	36.3	13,080	5.1	149,210	58.6
3	158,407	87,048	55.0	73,637	46.5	13,411	8.5	71,359	45.0
4	135,932	50,624	37.2	40,986	30.2	9,638	7.1	85,308	62.8
FOREST	632,920	300,182	47.4	258,985	40.9	41,197	6.5	332,738	52.6

* > 40% conifer, and > mature age.

9. Old-Growth Interior Forest Patch Size and Configuration Diversity

Concept and Rationale

Interior forest patches are zones described by the penetration of forest edge effects from the edge of a forest patch. Populations of forest interior species are adversely affected by the influx of generalist "weedy" species following increased fragmentation. Generalist species are favoured by the edge conditions of increased primary productivity, food, and cover, induced by fragmentation and increased total edge length (Whitcomb et al. 1976; Janzen 1986; Crow 1990). The distance of edge effect penetration depends upon the forest being analyzed (See "10. Forest Edge Length" for a discussion of the penetration of edge effects into forest interiors.)

Structure of the Indicator

A minimum limit of 60 m for penetration of edge effects is recommended here for use within the old-growth interior indicator in boreal Ontario. As it is expected that edge effects in the boreal forest matrix are relatively less severe than in an agricultural matrix (Angelstam 1986), the minimal edge distance used by other researchers (60 m) was chosen for this boreal application. Once interior forest patches are delineated through a buffering process, the sizes and complexity of the patches, and their total area, can be determined, as described above (see Table 14). This process has been utilized for a similar purpose in the northern Great Lakes region in Wisconsin (Mladenoff et al. 1994). Maps, at regional and forest scales, are useful to illustrate the distribution and configuration of interior forest patches.

Data and Analysis Requirements

data format: vector
data for entire forest contained in the same data coverage
coverages: roads, forest
buffering function

Old-growth Forest Patch Size, Interior Patch Size, and Configuration Diversity: Case Study

Analysis for Case Study

The area of > 40% conifer forest greater than mature age (here termed "older forest") was measured for each forest region and for the entire FMU (Table 14). In this study both the mature and old-growth development stages were tracked under the old-growth indicator. Maturity ages by species were determined based on Plonski yield curves (Plonski 1974) and species-specific physiological characteristics (Table 15). Old-growth ages for indicator purposes in the Spruce River forest (Table 15) were determined by reducing old-growth ages previously defined for species of the northeastern Ontario boreal forest (Brennan 1991), to include mature forest that will soon enter the old-growth stage. This was done in order to (a) compensate for the harsher conditions of northwestern Ontario, and (b) to include forest in the pre-old-growth stage that have some characteristics of old-growth such as large tree size, scattered dead, damaged, and down trees.

The extent of interior old-growth conifer forest area was then determined. Patches of older forest > 40% conifer composition were evaluated for edge with the

Table 15: Maturity and old-growth ages by species for the boreal forest of northwestern Ontario.

Species	Maturity Age	Old Growth Age*
Sb, Sw	> 60	> 110
Pw, Pr	> 40	> 120
Pj	> 40	> 80
B	> 40	> 60
Ce	> 80	> 120
L	> 60	> 100
Po	> 40	> 70
Bw	> 40	> 80

* Adapted from Brennan (1991)

use of a height edge rule (see "10. Forest Edge Length"). An interior buffer of 60 m was then applied to patch boundaries identified as edge. Edge forest area is the area within the interior buffer strip, and is the difference between total older conifer forest area and interior conifer area. "Other forest area" is the difference between total forest area and older conifer forest area. These data were then displayed by region and the FMU with a histogram (Figure 20).

Region 3 was selected for further analysis of old-growth and interior forest. A revised forest classification was devised for the region based on cover type (conifer, mixedwood, hardwood) and age class (mature, old-growth). In addition, roads were overlayed and contributed to patch formation. Maps were created to show the landscape patch configuration of various old-growth-related forest types (Figure 21) and interior forest (Figure 22). The region was classified into 20-ha patch size classes for older conifer forest, greater than 40% conifer composition (Appendix 3.3). Patch size-class distributions for area and patch number were displayed (Figures 23 and 24).

Results

The area of older > 40% conifer forest ranges from 37% in region 4 to 68% in region 1, and is 47% for the entire FMU (Table 14 and Figure 20). For area of interior forest, there is a range between 30% by area for region 4 and 62% for region 1, and 41% for the FMU. The amount of edge forest, or the area of interior forest lost due to edge, ranges from a low of 5% in region 2 to a high of 8% in region 3.

The patch size-class distribution for number of stands for region 3 exhibits a negative exponential form (Appendix 3.3 and Figure 24). The low end of the patch

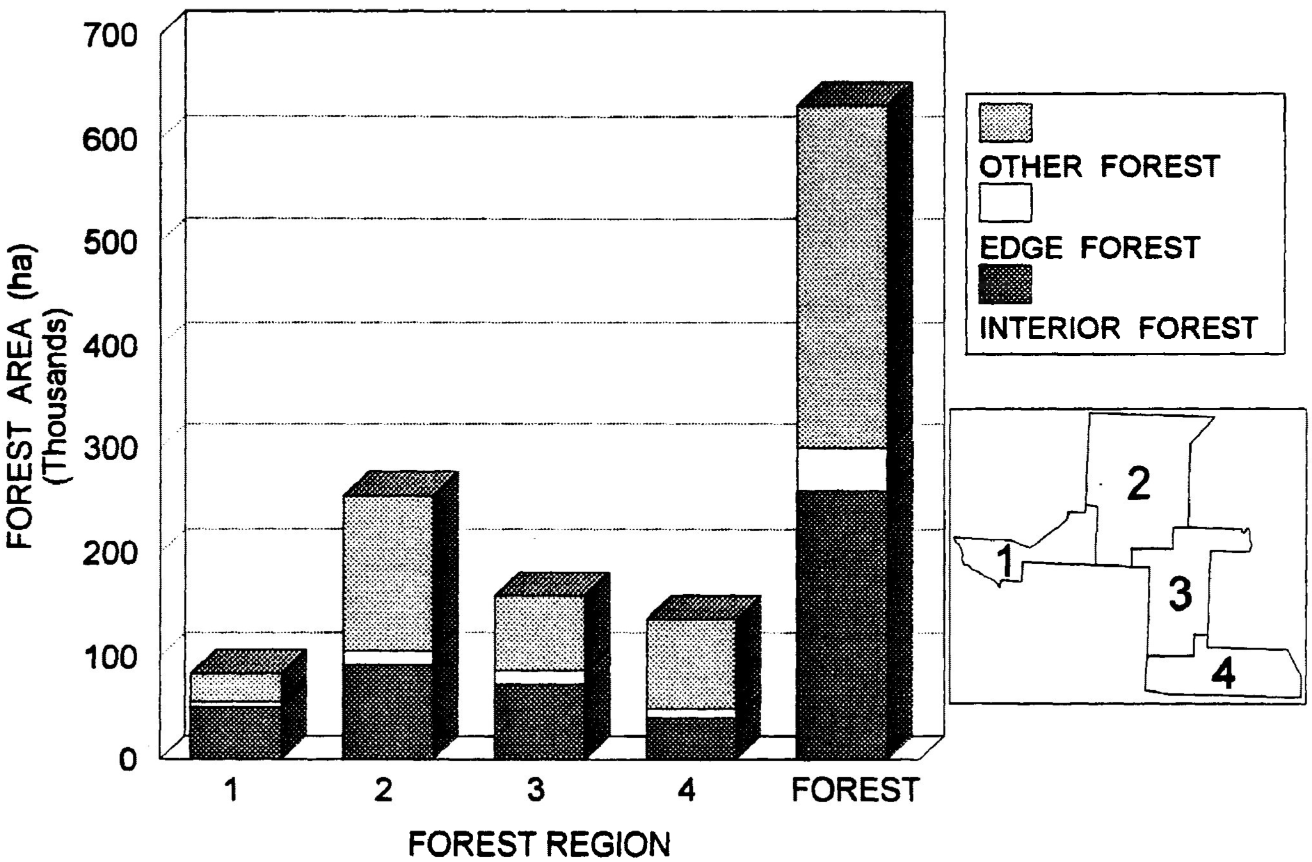


Figure 20 : Area of > 40 % conifer interior and edge old growth and mature forest combined, in relation to other forest area by region, for the Spruce River forest.

Figure 21: Old – growth and potential old – growth conifer and mixed wood for Region 3 of the Spruce river forest.

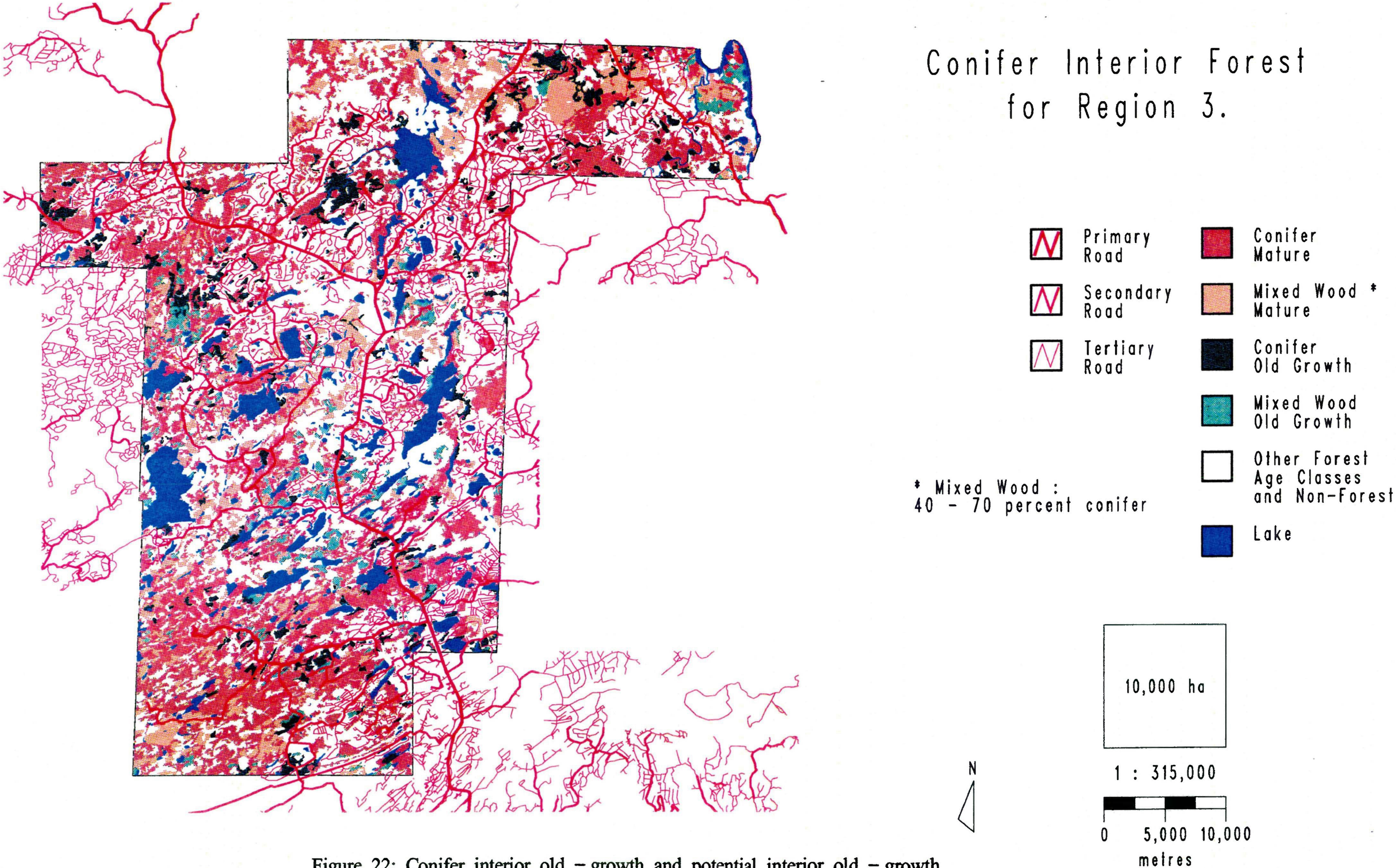
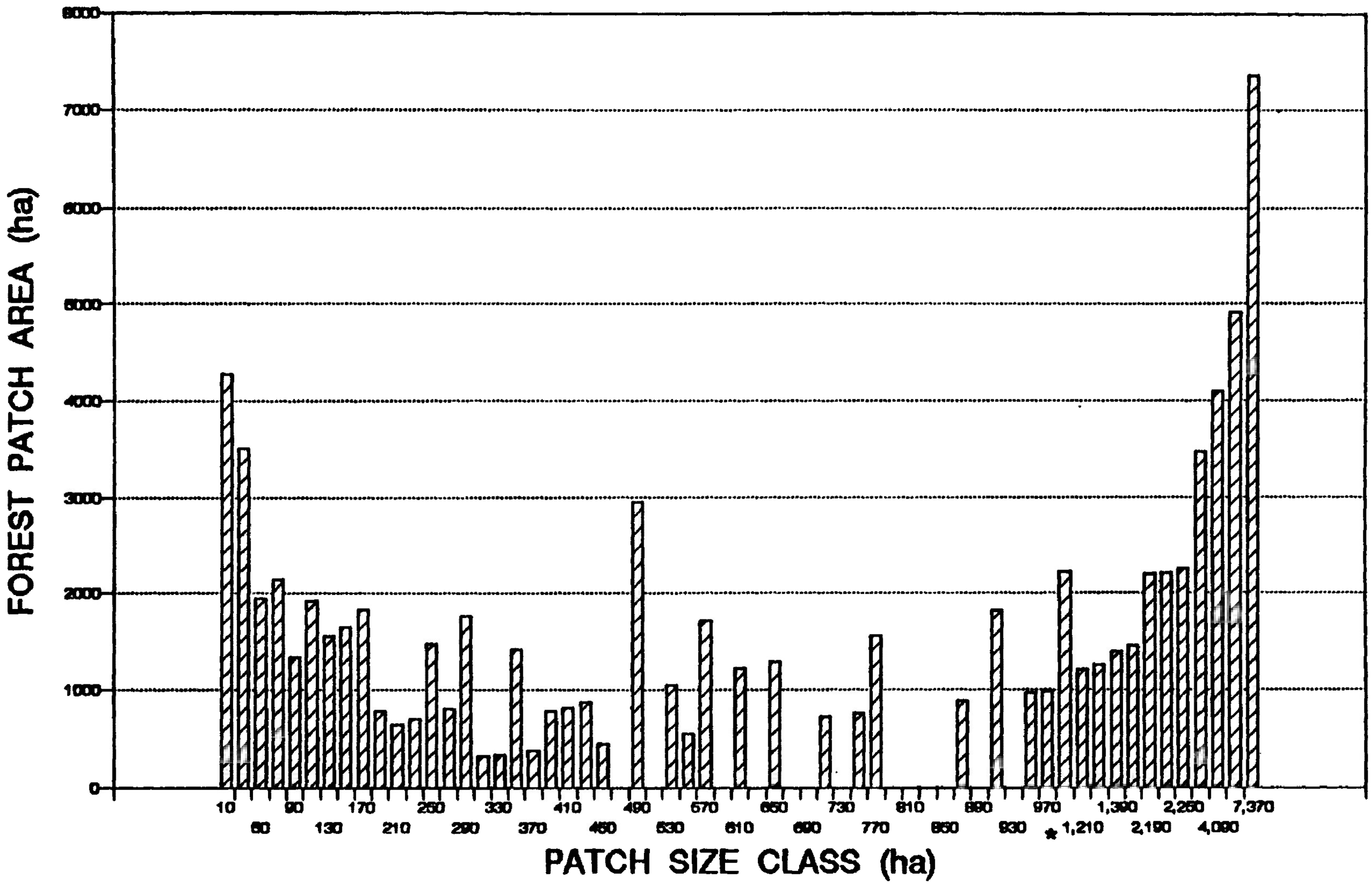
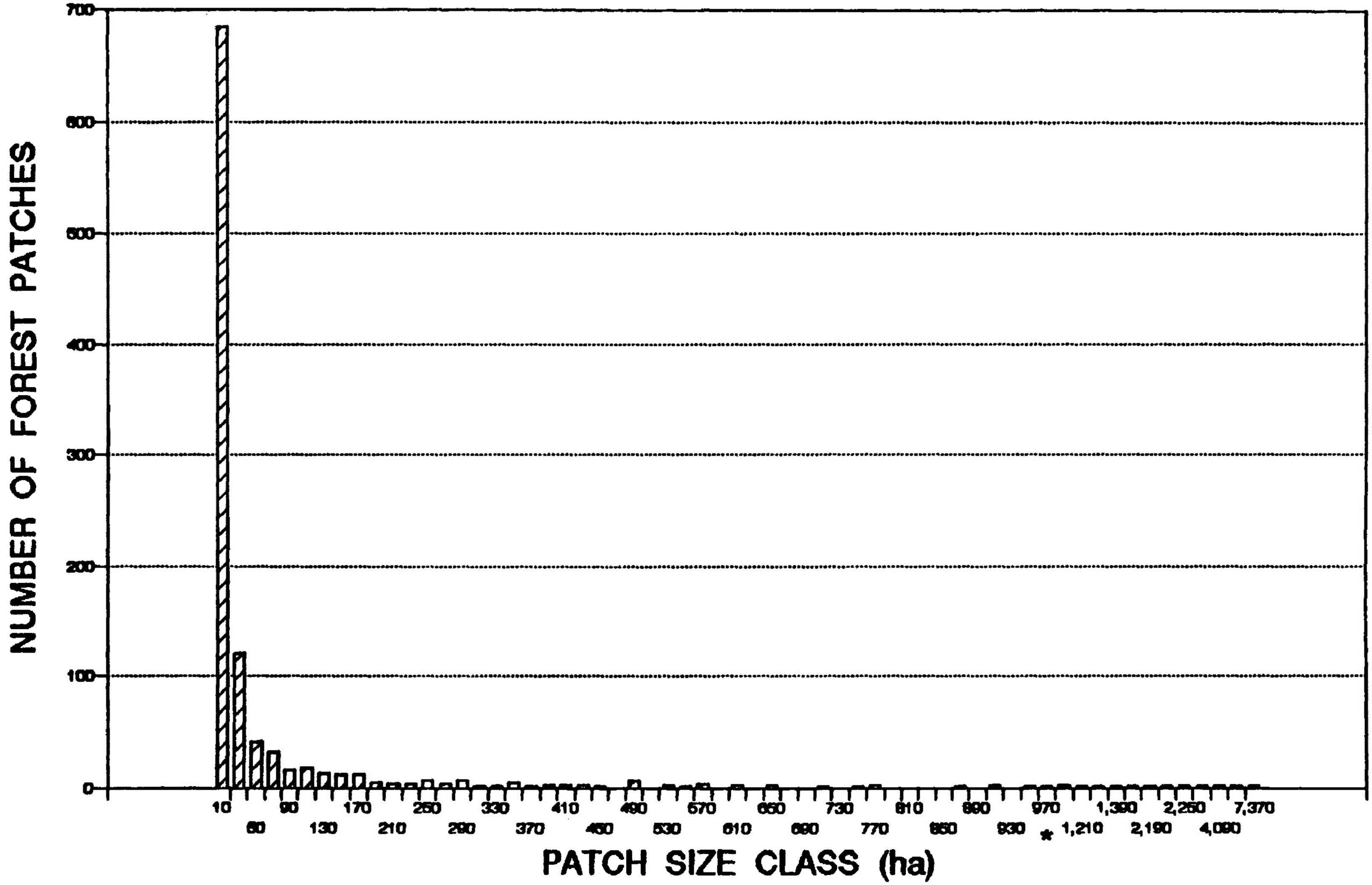


Figure 22: Conifer interior old – growth and potential interior old – growth (mature) forest for Region 3 of the Spruce river forest.



* Above 970 ha, size classes are not sequential.

Figure 23 : Patch size class distribution for patch area, for > 40% older conifer forest, for Region 3 of the Spruce River forest.



* Above 970 ha, size classes are not sequential.

Figure 24 : Patch size class distribution for patch number, for > 40% older conifer forest, for Region 3 of the Spruce River forest.

size-class distribution for area (Figure 23), below 100 ha, holds a significant amount of area, but this is surpassed by the area in the large patch size-class range. There is significant representation across the medium size-class range (200-770 ha) as well.

In comparison to the patch size-class distribution for forest patches of all types in region 3 (Figure 18), the distribution for older forest is fairly similar in form, except area is somewhat more evenly distributed across size classes, and there is less total area.

Old-growth conifer and mixed-wood forest is concentrated in a few geographical areas throughout region 3, in relatively small patches of generally no greater than 200 ha (Figure 21). In most cases it is road-accessed and is being fragmented by logging. When considering mature conifer and mixed-wood together in one category with old-growth, the southern one-third of region 3 holds a very significant tract of up to 20,000 ha in size. As well, there are a couple of large tracts of relatively uninterrupted forest in the north, 5,000-10,000 ha in extent.

Interior older conifer and mixed-wood forest combined for region 3 has a very similar geographic distribution to older conifer and mixed-wood forest combined. Interior patches are smaller in size, and therefore there are greater expanses between interior patches.

Interpretation and Evaluation

Region 4 has both the lowest proportion of older forest and interior forest since it is the most intensely logged region in the forest. Region 2 contains a low proportion of interior forest (36%) due to its large burn area. This will increase significantly in the future once the burn area matures. When considering regions 2, 3, and 4, it is difficult to discern a relationship between logging verses fire and the level of interior and edge forest. Perhaps any pattern is clouded somewhat by the logging that has occurred in region 2, in addition to its large expanse of burn. The differences in natural landscape diversity of the three regions may also be influencing the data. Perhaps this indicator should be accounting for the change in landscape diversity (change in interior and edge forest area) particularly due to timber management activity.

The patch size-class distribution for region 3 likely presents a more ecologically meaningful model of the landscape than an FRI stand size-class distribution, since it is based on more ecologically sound factors.

Interior older conifer and mixed-wood patches in the smaller size range may be less viable for interior old-growth wildlife species. There is generally a reduction of area available for interior old-growth wildlife species.

An important question to investigate is how the inherent size-class distribution for area has been altered by logging. Tracts of continuous forest are being fragmented by current logging. The extent of fragmentation to the landscape in 10-20 years will depend upon whether contiguous clearcutting is practiced in the future.

If old-growth values, related to vast tracts of interior old-growth, are to be maintained over time in this region, or in conjunction with adjoining regions, the remaining large tracts will need to be reserved, and large tracts of young healthy forest must be established for the sake of future large tracts of old-growth.

10. Forest Edge Length

Concept and Rationale

Generally, edges occur where two ecosystems come together (Hunter 1990). "The greater the contrast between two ecosystems, the more likely the adjoining habitats are to be very different in structure and in the wildlife species they support" (Hunter 1990). Climatic changes within some edge habitats result from hot, dry air passing into forest patches from adjacent open areas (Harris 1984; Kittredge 1973). Interior plant species not adapted to these conditions are replaced by open-habitat species, and trees are subject to blowdown (Wilcove 1987).

Current forest management practices generally lead to a significant increase in forest edge by fragmentation of large expanses of forest into habitat "islands" (Harris 1984; Hunter 1990; Franklin and Forman 1987). Timber management strategies in Ontario have promoted increasing edge through application of moose habitat guidelines (OMNR 1988). New strategies for maintaining biodiversity prescribe the measurement and reduction of edge, to meet the habitat requirements of interior forest habitat species (Duckworth and Fleming 1993).

Two major consequences of edge are of ecological importance: the so-called "edge effect" on habitat, and the influence of edge on flows across the landscape. The "edge effect" refers to the unique habitat formed where ecosystems meet. It often produces conditions of good food availability and cover in proximity, which is attractive especially to habitat generalists such as deer and moose. Within edge habitats, interior forest habitat specialists are out-competed by the habitat generalists

(Whitcomb et al. 1976), which can disrupt regional biodiversity if edge is overabundant (Noss 1983).

The literature reports various distances of penetration of edge effects into forest interiors. In the Pacific Northwest (PNW) a three-tree-height rule-of-thumb, or 60 m, is considered adequate (Wilcove 1987). Some investigators in the eastern deciduous forest have used 100 m as the buffer width for edge effects (Temple 1986; Gates and Gysel 1978). In addition, faunal effects of increase in songbird nest predation due to edge could extend as far as 300-600 m inside a forest patch (Wilcove et al. 1986). Predation is caused by such birds as crows, grackles, and cowbirds that enter forest edges and prey upon open-nesting interior bird species.

One question about the effect of edge on forest wildlife deals with the type of matrix surrounding forest patches or fragments, ranging from extensive forest to agriculture (Freemark 1988). Much of the original research was done in the Northeastern U.S., on forest successively fragmented into woodlots in an agriculture or urban matrix (e.g. Robbins 1979; Mayfield 1977). However, Wilcove (1988) concluded that findings of negative edge effects are relevant to extensive forest landscapes "because edges are precisely what clearcuts and wildlife openings create". Research in the Swedish boreal forest has shown that the predation effect of forest edge indeed depends upon the surrounding matrix. Levels of predation have been hypothesized to increase with the level of human impact on the landscape, ranging from forested to rural to urban lands (Angelstam 1986). Areas in central Sweden do not experience this effect, due to generally low productivity, and low intensity of agricultural activity, relative to southern Sweden.

Road creates artificial edge where it travels through productive forest (forest stands), resulting in the edge effects of encouraging opportunist species (Noss 1987). Roads dissecting large forest tracts can be barriers to the movement of wildlife (Oxley et al. 1974; Noss 1987) and other ecological flows. Edge, or ecotone, affects the flows of energy, nutrients and other materials, and organisms between landscape patches (Hansen et al. 1988a; Hansen et al. 1988b; Gosz 1991) much in the same way that cellular membranes vary in their permeability or resistance to flows (Wiens et al. 1985).

Edge is the cumulative result of a number of attributes of forest patches. Classifying forest edge into various types allows one to determine the quantity of edge for a specific purpose e.g. habitat for a particular species such as moose. In indicating forest sustainability, only edges created by management treatments, and natural edge that is ephemeral and changes as stands develop, are of interest. Thus, the edge associated with non-forested types such as muskeg and lakes, and any other relatively permanent types of edge, are not considered.

Types of Edge

The following five types and sub-types of edge can be useful in gauging ecosystem diversity in boreal forests: (a) hardwood/conifer edge; (b) height and stand structure edge - forest edge and road edge; (c) cover edge; and (d) stocking edge.

(a) Hardwood/Conifer Edge

Hardwood/conifer edge is the edge between hardwood and conifer cover types. Its existence depends, of course, on the definitions used for the two cover types.

(b) Height and Stand Structure Edge

The height/structure edge type is divided into two types: forest edge and road edge.

(i) Forest Edge

Forest edge, as a subclass of height/structure edge, implies that forest stands constitute the ecosystems on each side of the edge. Forest height and structure are the predominant stand characteristics that create edges where edge-effects occur. Forest edge occurs where open-canopy forest or low canopy height forest meets closed-canopy forest. The lowest stand height at which a forest can be considered to be closed-canopy for conifers and hardwoods is estimated, and forms the basis for determining the existence of this type of forest edge. The direct comparison of stand heights, as opposed to stand age, means that site class is considered within this edge category. Stand heights in the FRI are derived from photo interpretation and some field measures. The accuracy of FRI stand heights is adequate for calculating the height edge indicator (Birston 1993).

The characteristic tree forms of hardwoods and conifers are considered when setting the stand height criteria. Conifers are heavily branched until crown closure, while hardwoods have a more open form during their juvenile stage.

(ii) Road Edge

The second sub-component of height/structure edge is road edge. There is the potential for an edge to exist on both sides of a road because road clearance is a different type of ecosystem than the forest through which it passes. Road edge is therefore calculated as twice the length of primary and secondary roads. However, when non-forest land cover types and young stands comprise the ecosystems next to a road, there is no edge. Tertiary roads are not considered to contribute to edge in the medium to long term, as tertiary roads generally occur within clearcuts, are narrow, and will eventually experience closed-forest conditions, if they are abandoned.

(c) Forest Cover Edge

Forest cover edge relies on stand composition for its definition. However, not all stands delineated in an FRI as distinct, on the basis of composition, are sufficiently different from each other from an edge point of view. To account for this, a coarser classification scheme is called for (as appears in Appendix 7). This may be as coarse as the working group (Ontario FRI), or something more detailed to account for variations in the secondary species within working groups. One can use the detailed species composition data in the FRI to advantage here, and set rules such as: if the species composition of adjacent stands is less than or equal to 50% different, then the boundary is a cover edge.

(d) Stocking Edge

Adjacent stands of different crown closure (interpretable also as stocking level) can create edge. Crown closure or stocking, in most forest inventories, is measured relative to a fully stocked or fully closed stand (1.0 or 100%). Edge would be defined where adjacent stands had stocking levels sufficiently different, e.g., 0.4 units difference on the 0.1 to 1.0 scale.

Structure of the Indicator

In gauging the amount of edge in a forest, the above edge types can be calculated separately, or specific types can be combined. Edges that would be identified by two or three of the edge types might be considered to be ecologically more important than single-type edges.

Edges calculated according to explicit rules, that define edges of each type, can be mapped to display spatial patterns. Alternatively, edge lengths by type can be determined and prorated to a per-unit-area basis (edge density), for comparison of the forest patch complexity of different regions within a forest (Table 16). The OMNR has begun to acknowledge the importance of the edge:area ratio (Watt and Parton 1992). Map ledgers can provide explicit edge length and edge density information (Figure 29). The coincidence of edge types (net edge) can also be tallied as the lengths where specific types coincide (see Table 17). Edges have also been measured more directly using raster-based GIS techniques with remotely sensed data (Johnston and Bonde 1989).

Data and Analysis Requirements

data format: vector
data for entire forest contained in the same data coverage
coverages: roads, forest

Analysis for Case Study

Edge rules were created (Appendix 9), for the four forest edge types (identified above), by combining knowledge of the phytosociology of boreal tree species and the theory of forest edge. The edge rules were then applied to the cover types derived from the FRI, to establish the network of edge for the FMU landscape. Maps were plotted to determine the validity of edge and non-edge. Adjustments were made to

Table 16: Edge density for edge types, by region, for the Spruce River forest.

FOREST REGION	AREA (ha)	EDGE DENSITY (km/10,000 ha) EDGE TYPE					TOTAL *
		HW/SW	HEIGHT	ROAD	COVER	STOCKING	
1	106,531	81.0	90.0	10.8	175.3	133.0	409.1
2	302,516	53.6	92.5	8.7	183.6	99.4	384.3
3	180,642	121.6	171.0	21.8	190.6	197.7	581.1
4	152,640	121.5	183.4	20.1	171.7	178.1	553.4
FOREST	** 742,329	88.0	130.0	14.5	181.7	144.3	470.5
% OF TOTAL	NA	NA	27.6	3.1	38.6	30.7	100.0

* Includes all edge types except HW/SW.

** 24,000 ha of unclassified cutover not included

Table 17: Net edge density for edge type combinations, by region, for the Spruce River forest.

FOREST REGION	AREA (ha)	NET EDGE DENSITY (km/10,000 ha)			
		EDGE TYPE COMBINATION			
		HT-STOCK	STOCK-RD	HT-R	HT-STOCK-RD
1	106,531	157.0	143.8	100.8	167.8
2	302,516	145.7	108.1	101.3	154.4
3	180,642	229.6	219.5	192.8	251.3
4	152,640	231.8	198.2	203.5	251.9
FOREST	* 742,329	185.4	158.9	144.5	200.0

* 24,000 ha of unclassified cutover not included

the edge rules so they better reflected the ecological basis for edge. The edge rules were retested for several iterations until they were satisfactory. The edge networks were mapped for each edge type (Figures 25-28) and for the three-way combined net edge for region 2 (Figure 29).

Following establishment of networks of various edge types for the forest, the quantity of edge was measured. Total length of edge was determined for the five edge types by basemap (Appendix 3.4). Edge values were then totalled for the five edge types, the four regions, and for the entire forest, and prorated to a 10,000 ha basis (edge density) (Table 16). Similar operations were performed for the pair-wise and three-way net combinations of the following: the two sub-types of height and structure edge (height edge and road edge), and stocking edge (Appendix 3.5; Table 17). The particular triple combination of edge types was chosen as a demonstration of the calculation of the net effect of these three important types contributing to edge effects.

The data for edge and net edge were graphed to determine the relative contribution of edge density and net edge density between types and regions (Figures 30 and 31). The basemaps of the FMU were then classified into net edge density (NED) classes (Table 18). A map was also produced of the basemaps of the forest classified into the above NED classes (Figure 32).

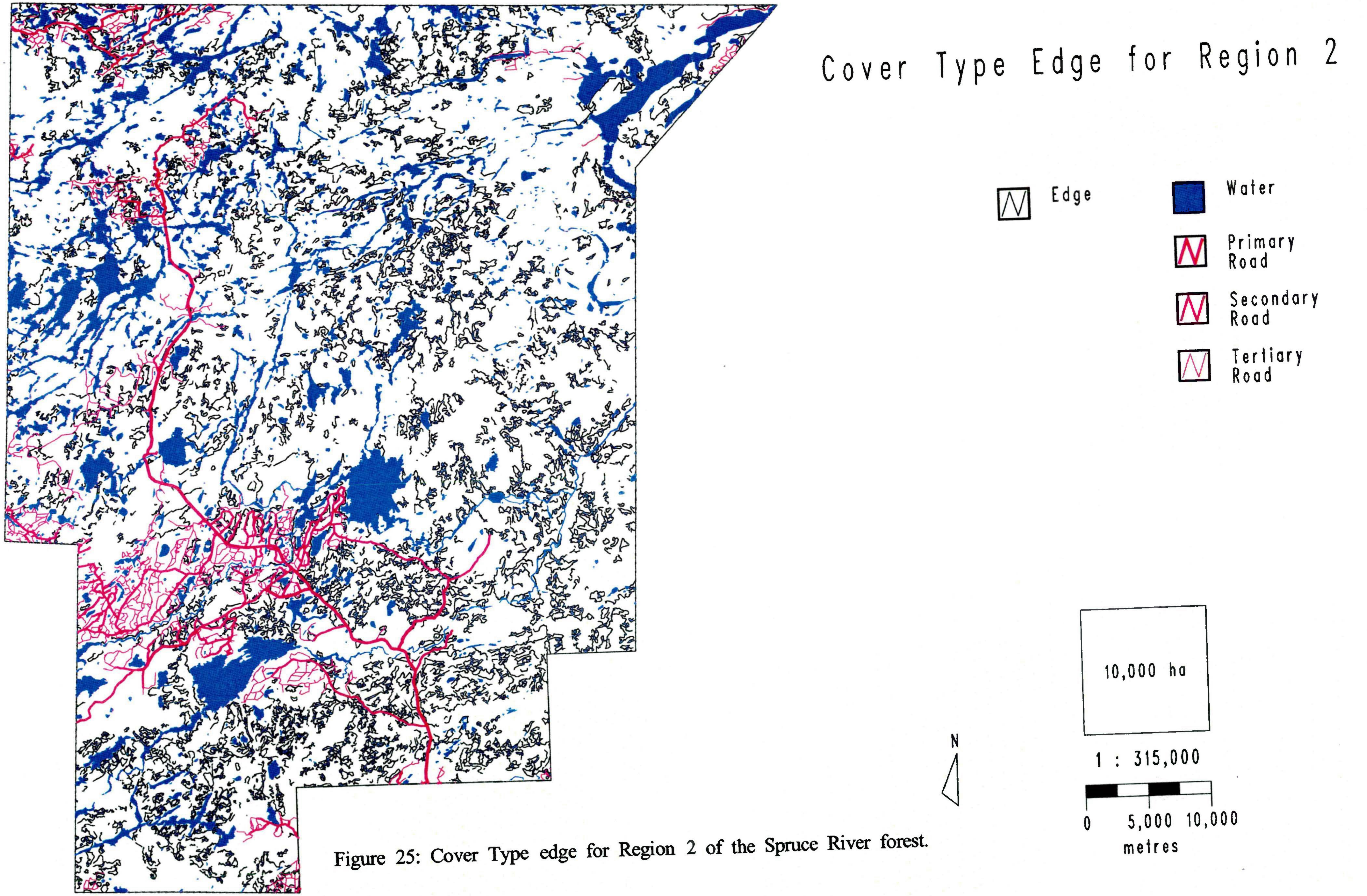


Figure 25: Cover Type edge for Region 2 of the Spruce River forest.

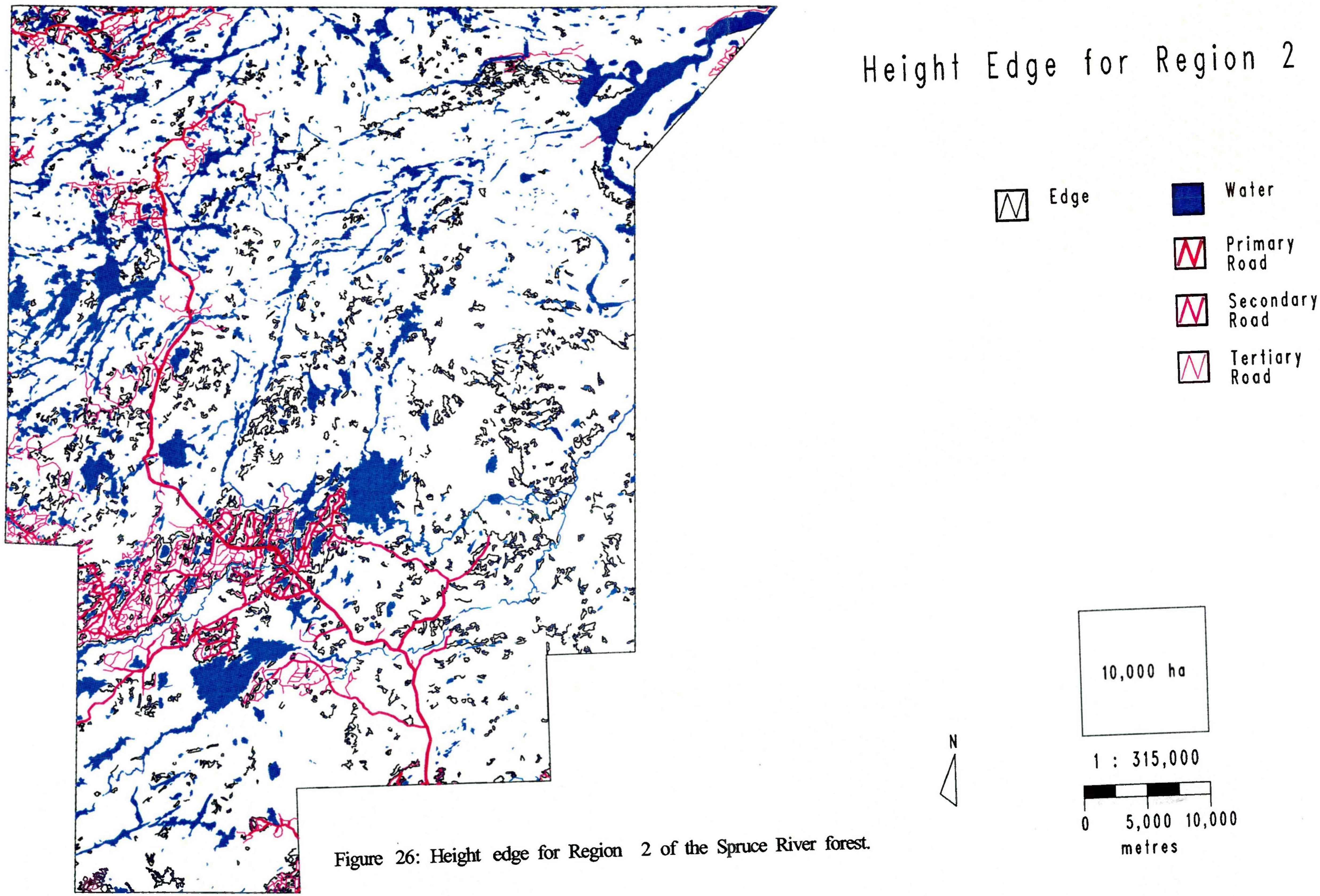


Figure 26: Height edge for Region 2 of the Spruce River forest.

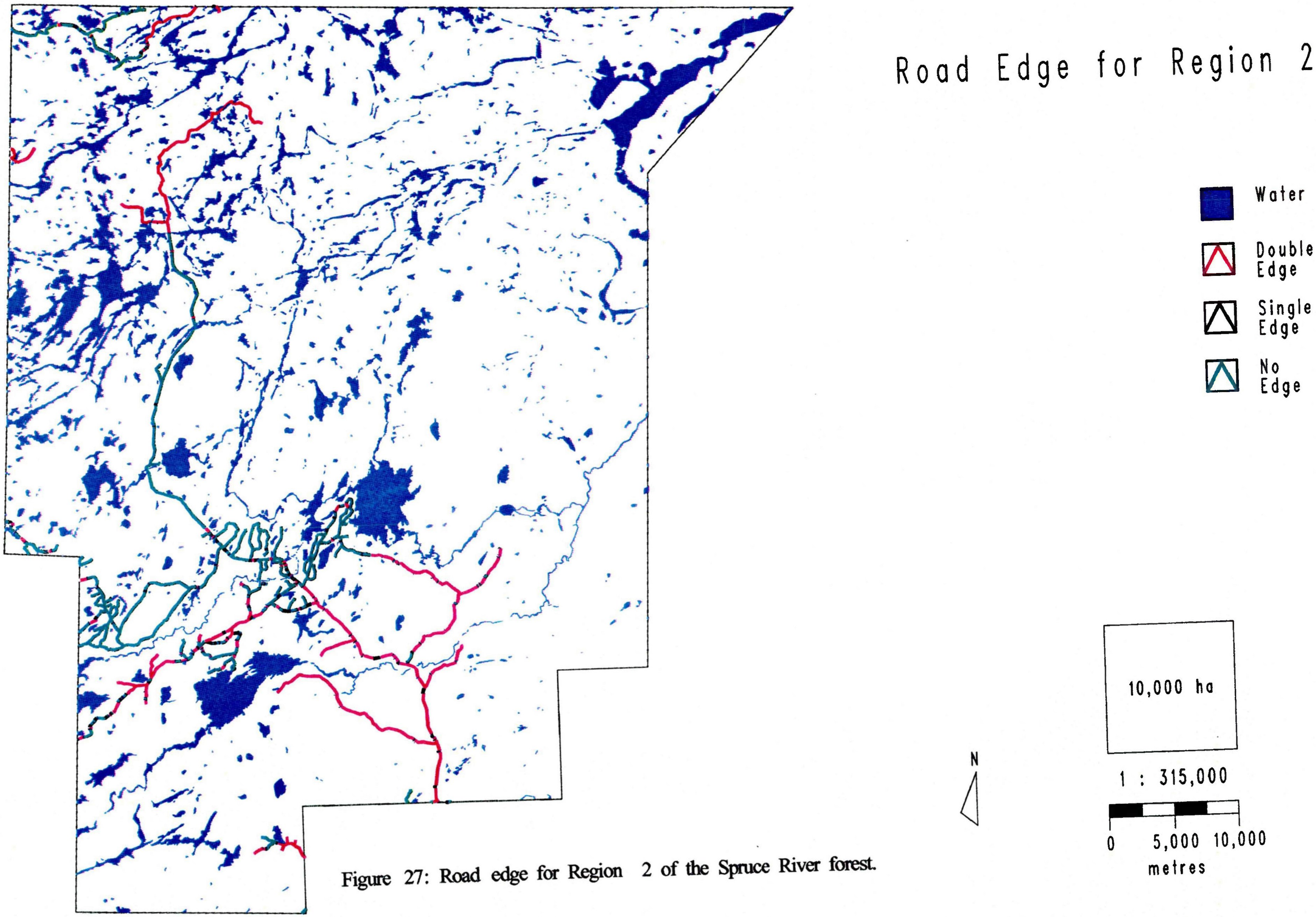


Figure 27: Road edge for Region 2 of the Spruce River forest.

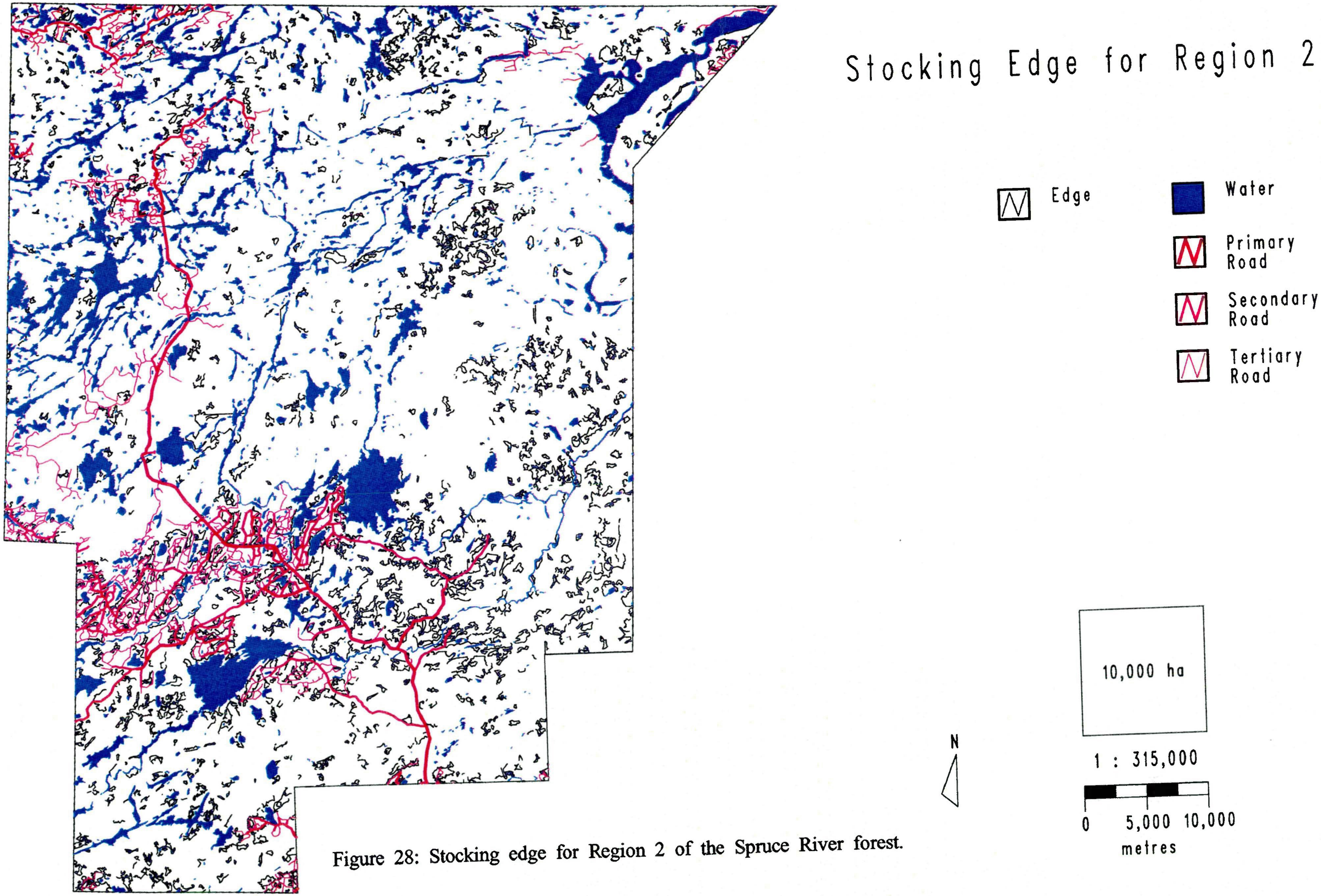
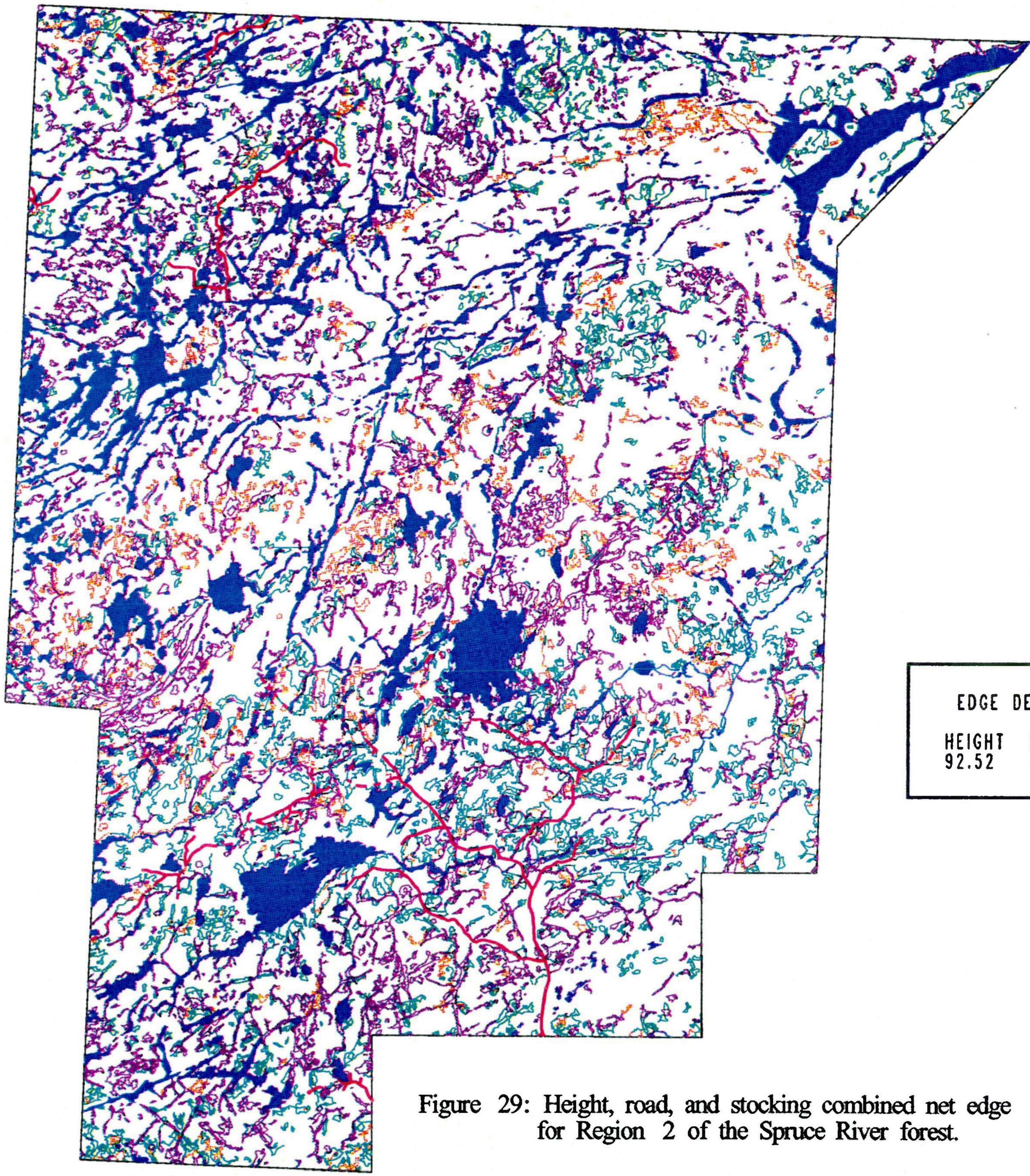


Figure 28: Stocking edge for Region 2 of the Spruce River forest.



Height, Road, and Stocking Net Edge for Region 2

Non-forest
Water
Road Edge
Height Edge
Stocking Edge

EDGE DENSITY (km/10,000 ha)				NET EDGE DENSITY (km/10,000 ha)				
HEIGHT	STOCKING	ROAD	TOTAL	HT-STOCK	STOCK-RD	HT-RD	HT-STK-RD	TOTAL
92.52	99.38	8.74	200.64	145.65	108.12	101.26	154.39	

N

10,000 ha

1 : 315,000

0 5,000 10,000
metres

Figure 29: Height, road, and stocking combined net edge for Region 2 of the Spruce River forest.

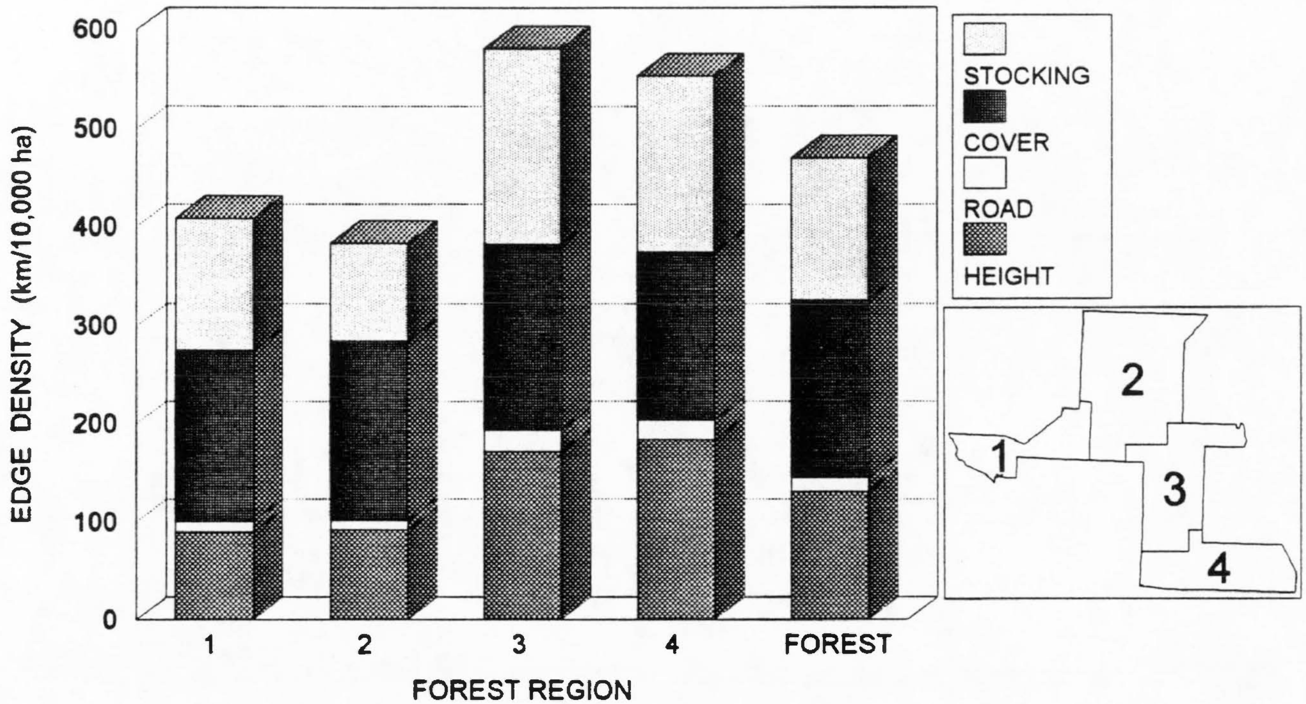


Figure 30 : Edge density by edge type and forest region, for the Spruce River forest.

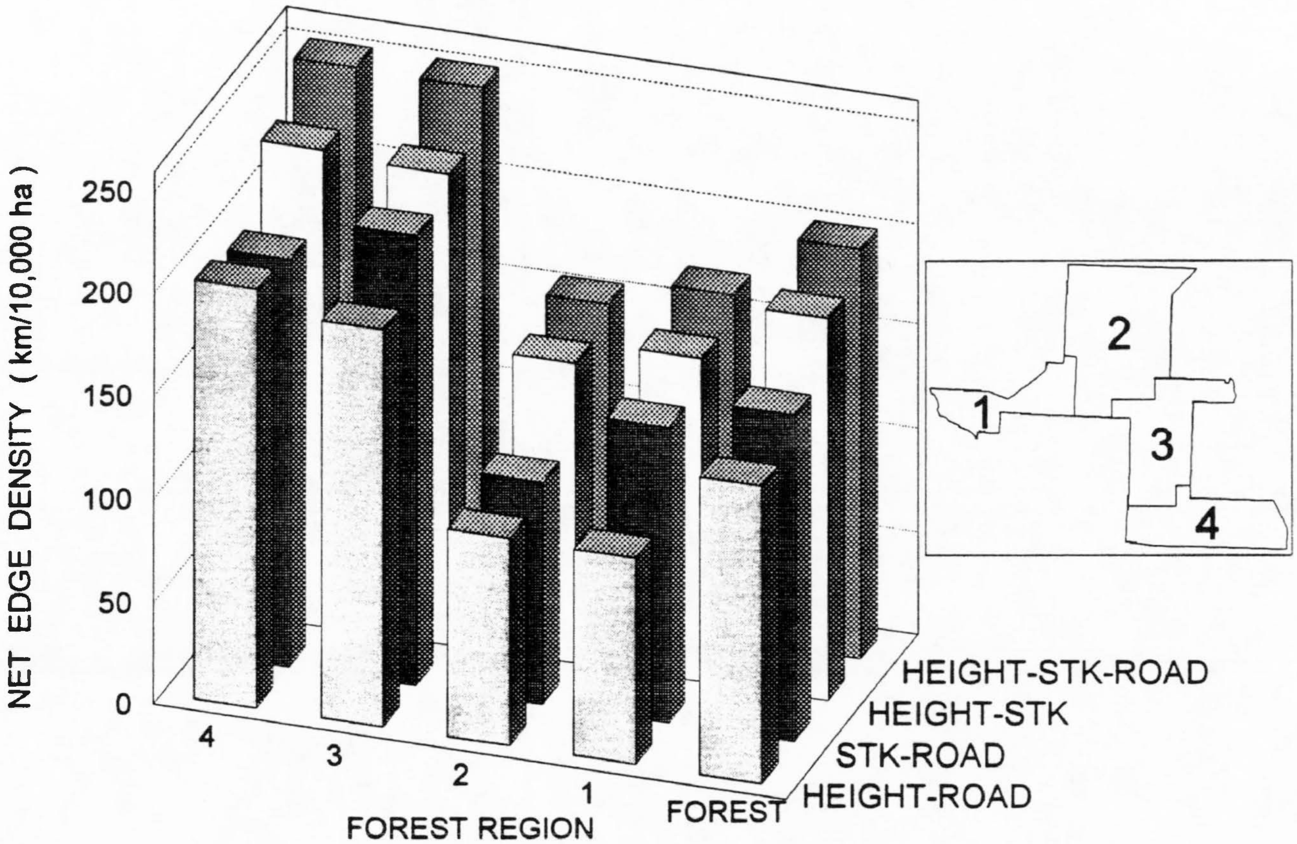


Figure 31 : Net edge density by edge type combination and forest region, for the Spruce River forest.

Table 18: Area of the Spruce River forest within net edge density classes for height - stocking - road net edge.

HT-STK-RD NET EDGE DENSITY CLASS (km/10,000 ha)	AREA (ha)	PERCENT AREA (%)
0-75	65,851	8.6
75.1-150	178,613	23.3
150.1-225	254,775	33.3
225.1-300	145,309	19.0
300.1-375	107,604	14.0
375.1-450	13,908	1.8
>450.1	65	0.009
FOREST TOTAL	766,125	100

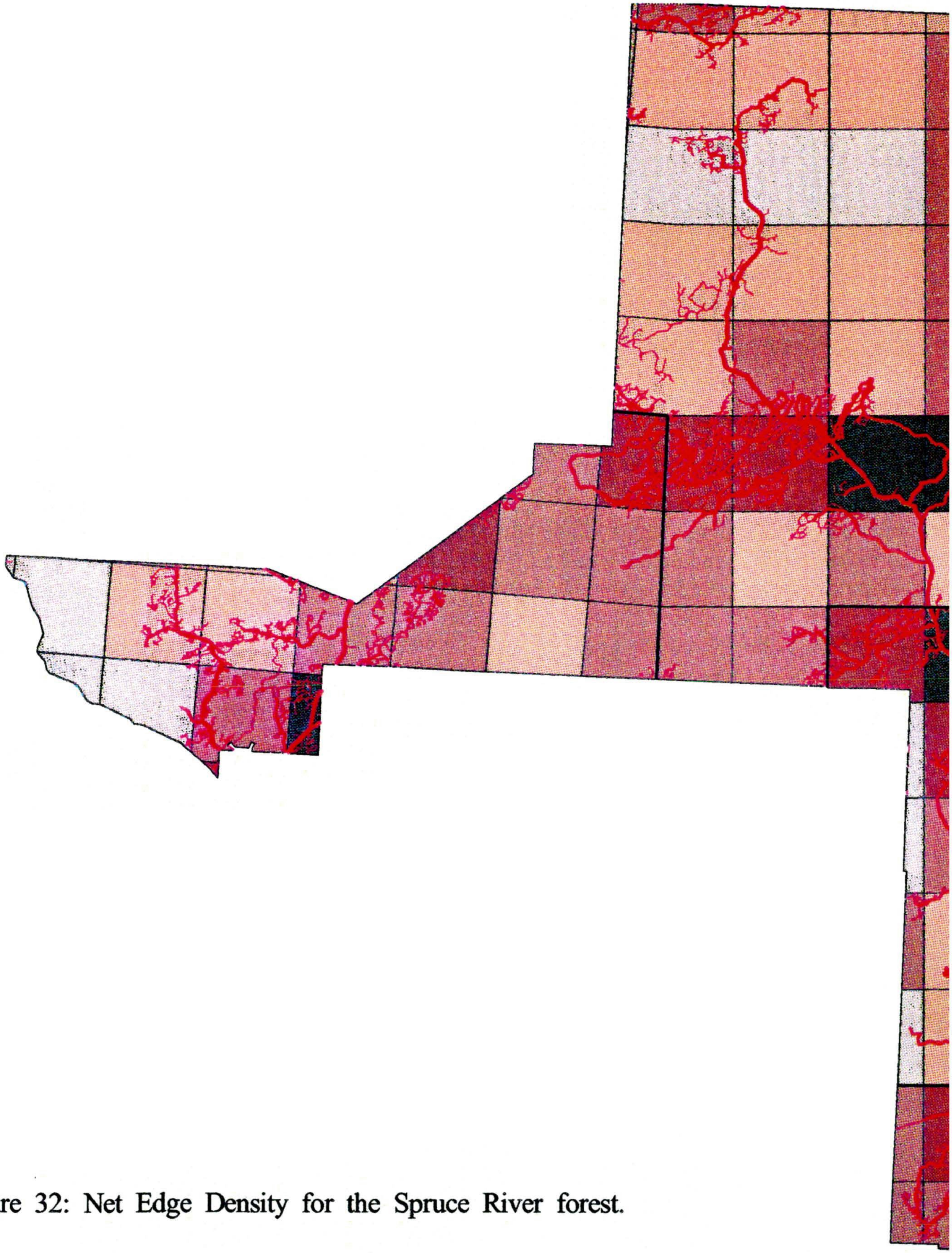


Figure 32: Net Edge Density for the Spruce River forest.

Net Edge Density

<u>Results</u>

The edge types in Table 16 can be separated into two general categories: those directly related to edge effects (height, road, and stocking), and those related to forest cover (HW/SW and cover). The regions of the forest do not differ much in their level of cover edge density, while HW/SW edge density is significantly higher in the two southern-most regions.

In region 2, cover-type edge forms the most extensive edge pattern of all edge types. There is a swath of higher concentration of cover-type edge that runs across the bottom end, up the east side, and curves to the centre (Figure 25). The middle to northern part of the region is generally lower in density of cover edge including the burn, except the swath through the centre.

Height edge in region 2 (Figure 26) is at a low level compared to regions 3 and 4 (Figure 30), and is found in higher densities in timber management areas and as remnant clusters of stands in the burn in the northern half.

Stocking edge in region 2 (Figure 28) occurs as major concentrations in irregular patches within a wide band across the southern half, including a timber management zone, and the lower east side. A few other small scattered patches are present: one in the extreme north, a patch within the burn, and small patches in the south.

Road edge in region 2 (Figure 27) corresponds to much of the primary and secondary road network in the south, and about half of the sparse network in the north. Roads through the burn do not appear as road edge.

The map of the three-way combination of edge types for region 2 (Figure 29) reveals that the major concentration of the edge network is in the wide band that crosses the southern half of the region and turns part way up the east side. The combination of height, stocking, and road edges results in an average net edge density of 154 km/10,000 ha.

Among the edge-effect-related edge types, height edge and stocking edge contribute similar magnitudes to total forest edge density of roughly 30% each, while road edge density accounts for 3% (Table 16 and Figure 30). Regions 3 and 4 contain, on average, 43% higher total edge density than the two more northerly regions. Stocking, road, and height edge density (edge-effect-related edges) are significantly less in the northern two regions. Road edge density is more than twice the level, on average, in the southern two regions as that in the north. Road edge density is greatest in region 3, and lowest in the northern region 2.

Among the three pair combinations of NED types, height-stocking has the highest level of NED for the total forest, as well as for every region (Table 17 and Figure 31). Stocking-road and height-road are of similar magnitude for all regions, and the total forest, except for region 1 in which stocking-road is 43% larger than height-road. Considering all four NED combinations, including height-stocking-road, regions 3 and 4 possess significantly higher NED levels, varying between, on average, 51-95% higher for height-stocking and height-road, respectively.

Edge length and net edge length calculation, for each basemap for all edge types, varies widely from 0 to the 100's of kilometers (Appendix 3.4 and 3.5). Some of the wide variation is correlated to variations in basemap area.

The classification of height-stocking-road NED by basemap (the final column of Table 17) into 50 km/10,000 ha NED classes appears in Table 18 and Figure 33.

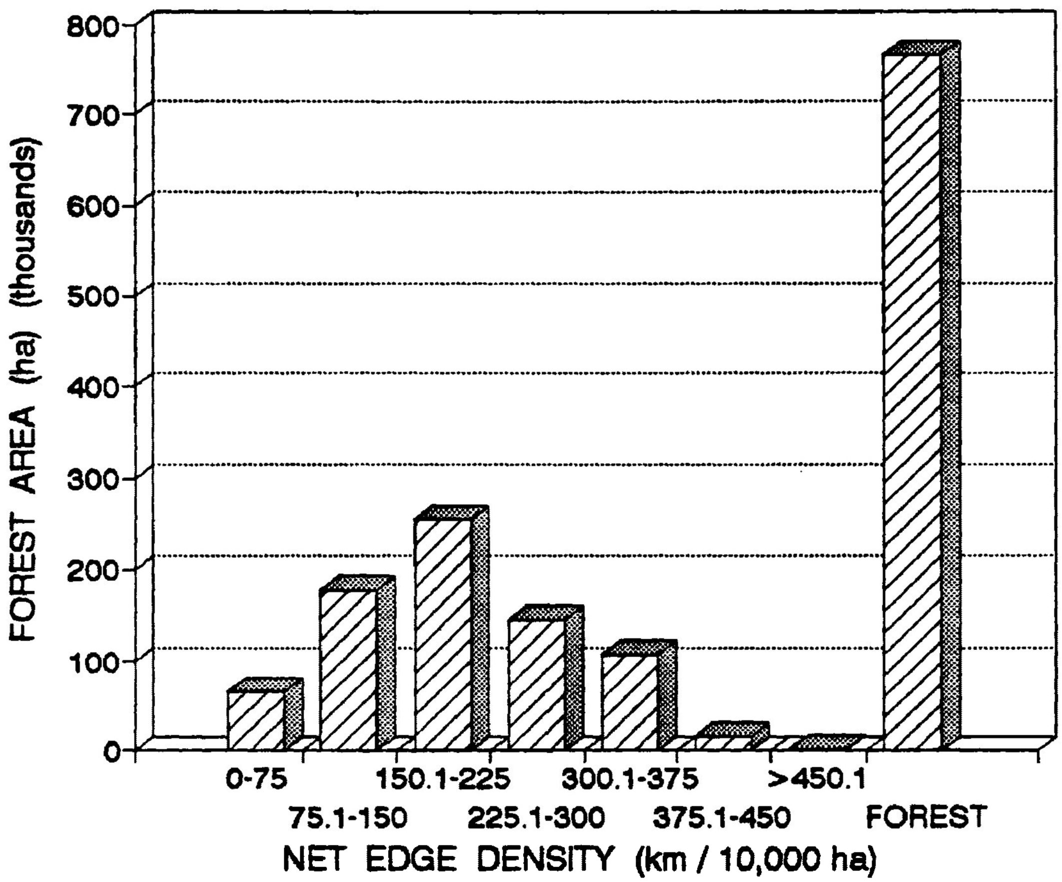


Figure 33 : Area within net edge density classes for height - stocking - road edge, for the Spruce River forest.

The area distribution of NED classes peaks in the 150-225 km/10,000 ha class with 255,000 ha or 33% of the forest. The highest NED class with significant forest area is 300-375 km/10,000 ha with 108,000 ha.

There are several sections of high NED across the forest: two large sections that make up much of the southern regions 3 and 4, a band through the southern half of region 2, and small pieces in region 1 (Figure 32). These high NED sections generally correspond with areas of high timber-management activity as indicated by road density. An exception is the mid-level NED class containing the most area, which occurs throughout the forest, in both treated and untreated areas. Also, some of the basemaps within the second lowest, and to a lesser degree the lowest class, do contain some roads.

Interpretation and Evaluation

The spatial distribution of stocking and height edge in region 2 appear to be related to natural landscape pattern, as well as timber management activity linked to roads. Road introduces a new permanent double edge where it did not occur previously on the natural landscape, potentially creating new obstacles or barriers. A target for planning could be to mimic the natural landscape edge pattern for each edge type.

The two southern regions have a more complex landscape than the northern regions, judging by their higher edge and net edge densities for most edge types and edge-type combinations. Also, there is a general correlation between basemaps with high NED and high levels of timber management activity. Therefore higher levels of timber management activity may be a large contributor to higher landscape edge complexity. The regional and forest totals and averages could be compared to natural forest areas to determine their variation from a natural landscape.

Edge density is much more useful than edge length as an indicator since it makes possible the direct comparison of landscape complexity between zones within the FMU, and to other forests. Also, simply totalling edge length of different edge types, to arrive at a total edge length, is not an effective measure since it does not account for the "net" effect of overlapping edges of different types.

The spatial distribution of NED across the FMU showed some anomolies in the expected pattern, as described above. These may be due, in part, to the structure of the indicator, as net edge is calculated on a per-total-forest-unit-area basis. In future stages of refinement for the edge length indicator, net edge should be calculated based on per-productive-forest-unit-area basis. This will account for variations in proportion of area of non-forest types, such as lakes and bogs, across the forest landscape.

11. Habitat Supply for Specific Species - Marten

Concept and Rationale

Habitat quality for specific forest-dwelling species can be characterized using suitability indices or carrying capacities (Greig et al. 1991). Habitat supply models (e.g. Wedeles et al. 1991; Duinker et al. 1993) are used to make index or capacity calculations based on habitat characteristics. In conjunction with forest-inventory simulators (e.g. Moore and Lockwood 1990) that forecast forest change in response to alternative management strategies, habitat supply models permit forecasting the effects of various forest management regimes on the habitat of specific species.

I propose that a useful species for gauging forest sustainability from a wildlife point of view is the American Marten (*Martes americana*). The marten has become a key species of concern for boreal forest managers (Thompson 1991; 1993). Marten prefer older coniferous forest habitats and are negatively affected by clearcut timber harvests (Thompson 1988; McCallum 1993). The effects of timber management on other species dependent upon old coniferous forest habitat can perhaps be approximated by tracking habitat supply for marten.

Structure of the Indicator

A marten-habitat supply model developed by McCallum (1993) for Ontario's boreal forest could be used to analyze the marten indicator. McCallum's (1993) model calculates habitat suitability indices (HSIs) on a scale of 0.1 (very poor) to 1.0 (excellent) for female marten in late winter. The forest landscape is analyzed in one-hectare pixels, with each pixel receiving an HSI rating for a particular year under a specific management scenario. HSI numeric ratings can be retained for results displays, or combined in some form of classification (e.g., excellent, good, medium, poor habitat). Results can be displayed on maps showing the spatial distribution of marten habitat quality, or in tables showing the area in hectares or percent area in each of the habitat classes.

The habitat components included in the marten habitat supply model are food, cover, reproductive sites, and spatial influences. Three variables represent cover requirements in the model: stocking, species composition, and age. Food availability is calculated in part with an HSI model for snowshoe hare (*Lepus americanus*) habitat, which in turn is related to stand age and species composition. The availability of denning and nesting sites is related to the age and composition of older stands. Spatial relations of food, cover, and denning/nesting sites are accounted for through a nearest-neighbour analysis.

Data and Analysis Requirements

data format: raster (1 ha resolution)
coverages: forest
stand data: height, stocking, age
disturbance types and silvicultural treatments
HSI model (McCallum 1993), suitably modified to apply specifically to the forest in question

INDICATORS RELATED TO ROADS

Roads may well create the greatest impact on the forest landscape of any forest-management-related activity. Several of the suite of indicators presented here relate to the impact of roads (e.g., wilderness classes, edge, fragmentation, road density, forest conversion). Roads may be evaluated for their impacts based on criteria of traffic volume, access, landscape/scenic beauty impacts, and permanence, all of which depend upon road class (Table 19).

12. Road Density

Concept and Rationale

The level of road access may be considered in two contexts. Road access is a benefit when it is desirable to reach particular forest resources by road, and realize values such as non-wilderness recreation or timber. Negative aspects of high levels of road access are related to impacts on wilderness-type values and interior wildlife habitat. As road density rises, fragmentation and edge-effects increase, and forest interior habitats decrease.

Roads alter ecosystem flow dynamics, both across roads and road edges, and along the route of roads themselves. It has been shown, for instance, that roadways

Table 19: Road characteristics by road class.

	Road Class		
	High		Low
	Primary	Secondary	Tertiary
Description	- all weather - paved or gravel graded	- all weather - gravel	- short-term use - some eventually rehabilitated - non-gravelled, unmaintained
Criteria			
1) Traffic	- high	- high	- low
2) Access	- high	- high	- high
3) Landscape/ scenic beauty impacts	- high	- high	- medium-high
4) Permanence	- long	- long	- short

inhibit the movements of small forest mammals, width of road clearance being the most important factor (Oxley et al. 1974). Access provided by roads to forest habitat is detrimental to woodland caribou populations (especially in the southern part of their range where densities are low) as people and predators are able to travel freely into these habitats (Darby and Duquette 1986; Stevenson 1986; Kansas et al. 1991). Furbearer populations decrease with increasing road density due to greater trapping pressure (Thompson 1988).

Structure of the Indicator

Road access is measured as kilometers of road, by road class, per 10,000 ha basemap (see Appendix 3.6). The pattern of road access across the forest can be illustrated by a map showing basemaps classified into road density classes. If a road network is efficiently planned, then length of road per unit area is a measure of the degree of access to forest resources and places.

Data and Analysis Requirements

data format: vector
data for entire forest contained in the same data coverage
coverages: roads, forest

Analysis for Case Study

Road access was measured as distance of road (in km) by road class, per basemap. This was then converted to km/10,000 ha since basemaps vary in size from the standard of 10,000 ha. Basemaps were classified into 50 km/10,000 ha road density classes (Table 20 and Figure 34), and their distribution across the forest mapped.

Results

The road density class with the greatest area is the 1-50 km/10,000 ha class which holds 253,000 ha (Table 20, Figure 34). The other four classes up to 200 km/10,000 ha are roughly even in area, holding 115,000 ha (or 15% of the FMU) each, on average. The largest road density class holding significant area is the 200-250 km/10,000 ha class, with 43,000 ha (or 6% of the forest).

There are large sections of relatively high road density in regions 3 and 4, with region 4 being virtualy all a high road density zone (Figure 35). Other small sections of high road density are found in the extreme north end of the forest, a band in the southern half of the northern region, and in region 1. The main road corridor runs right up to the more remote north end of the FMU. However, there are two substantial sections remaining which have yet to be thoroughly incised by roads: one in the central area of the FMU of about 70,000 ha, and the largest in the northeast of about 100,000 ha.

Table 20: Area of the Spruce River forest within road density classes.

ROAD DENSITY CLASS (km/10,000 ha)	FOREST AREA (ha)	% OF TOTAL (%)
0	116,266	15.2
1-50	252,615	33.0
50.1-100	105,789	13.8
100.1-150	124,502	16.3
150.1-200	115,127	15.0
200.1-250	43,429	5.7
>250.1	8,396	1.1
TOTAL	766,125	100.0

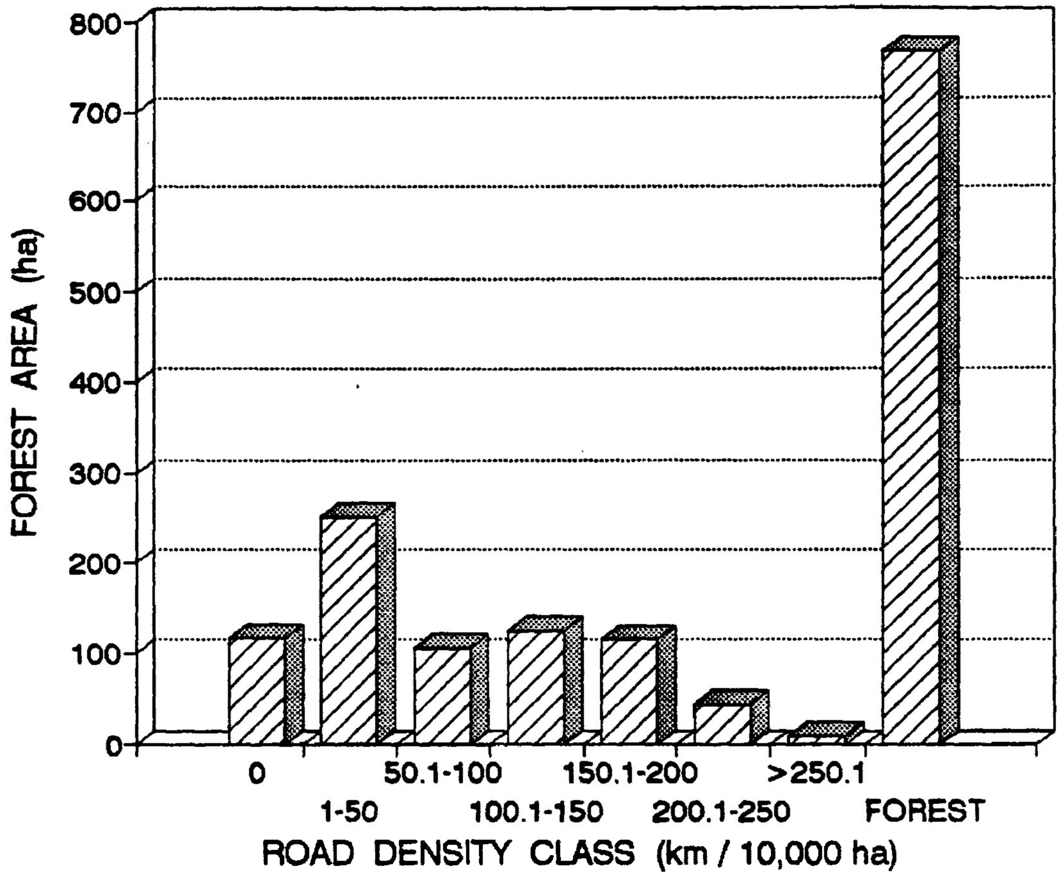


Figure 34 : Area within road density classes for the Spruce River forest.

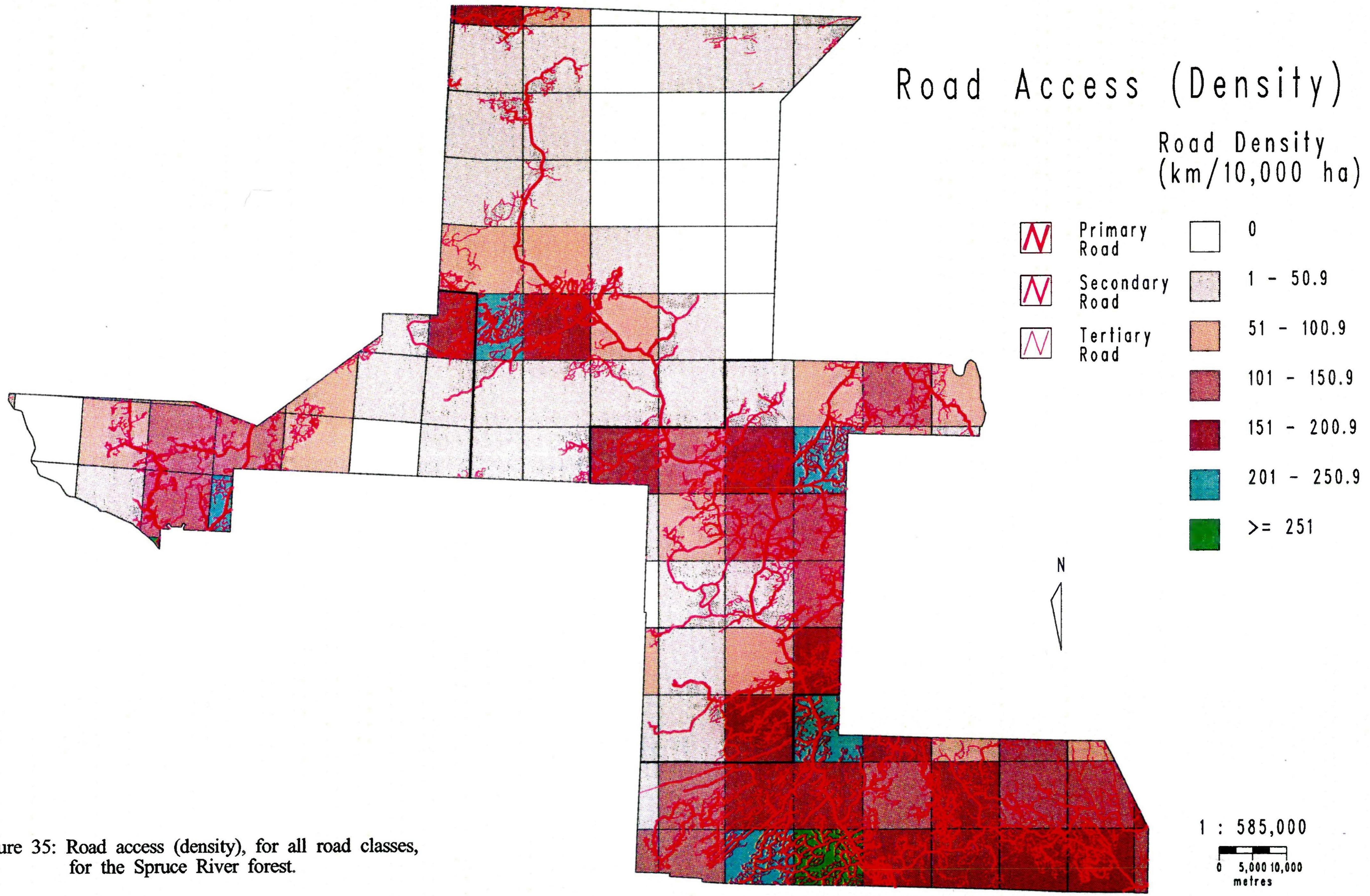


Figure 35: Road access (density), for all road classes, for the Spruce River forest.

Interpretation and Evaluation

Road density in the Spruce River Forest is correlated geographically with level of timber management activity per unit area since most roads are constructed for this purpose. High road density shows a geographic distribution similar to that of net edge density (Figure 32).

The forest has been thoroughly accessed in the highly concentrated, high road density sections in the south of the FMU. There is no longer potential for any large pristine roadless wilderness areas in the south. The two large roadless sections could be candidates for wilderness, where area- and human-sensitive wildlife, and other wilderness values, could be satisfied. Perhaps zones of various road density levels could be set throughout the FMU to provide for various values.

The accuracy of this indicator will be affected by the integrity of the road data. If the data are not up-to-date, some roads may be missing and some extra roads may be included that are old and inaccessible.

13. Forest Conversion by Roads and Landings

Concept and Rationale

Forest conversion due to roads draws a connection between road construction activities, related to timber management, and degradation of the forest ecosystem through conversion of forest cover to non-forest. Productive forest is lost, and there is a corresponding loss of production of forest outputs. Carbon storage capacity of the forest as a whole is diminished as well, due to the loss of biomass and biotic activity. While all bush roads (and landings as well - see below) will ultimately revert to forest cover given abandonment and sufficient time, the effects on forest ecosystem functioning are apparent at least in the short to medium term.

Landings, which are staging areas for timber management operations, and often associated with roads, also convert a significant proportion of forest into non-forest. In Manitoba, landings can convert between 1.9% and 4.6% of the productive forest, depending on the logging system and season of logging (Olson 1991).

Structure of the Indicator

This indicator shows the amount of forest land taken out of productive forest as a consequence of roads constructed for timber management purposes. Road construction, within each road class, converts a set width of forest along a length of road to both roadway surface and non-forest right-of-way (road clearance) (see Table 21). By including the entire width, from one forest edge to the other, significant areas alienated from the functioning forest ecosystem are accounted for in areas of concentrated timber management. Forest conversion due to roads, for each road class, is calculated by multiplying the average width of road clearance for a road class by the length of road, in a designated region of the forest (see Appendix 3.7).

Table 21: Road clearance for each road class.

Road Class	Road Clearance * (m)
primary	25
secondary	20
tertiary	10

* from Pulkki (1993) and Kromm (1993)

Data and Analysis Requirements

data format: vector
data for entire forest contained in the same data coverage, and forest regions delineated
coverages: roads, forest

Analysis for Case Study

The width of forest along a length of road that is converted to both roadway surface and no-forest right-of-way (road clearance) was established for each class of road (Table 21). Forest conversion due to roads, for each road class, is calculated by multiplying the average width of road clearance for a road class by the length of road, for each basemap in the FMU (Appendix 3.7). Basemaps were then classified into 50 ha/10,000 ha classes (Table 22), graphed to analyze the area distribution (Figure 36), and mapped for the FMU to analyze spatial distribution (Figure 37).

Results

The lowest two forest conversion classes below 50 ha/10,000 ha, or 0.5% forest conversion by area, contain 296,000 ha (39%) of the FMU (Table 22 and Figure 36). Forest conversion classes above 250 ha/10,000 ha, or 2.5% forest conversion by area, contain 67,000 ha (9% of the FMU). Sections of high levels of forest conversion occupy virtually all of region 4, the majority of region 3 in two major sections, a band in the southern half of the northern region 2, and a small strip in the north end, and a section of region 1. The most significnat area of low or no forest conversion is in the northern region, with another major concentration in a central section of the

Table 22: Area of the Spruce River forest within classes of forest area conversion by road clearances.

CONVERSION CLASS	FOREST AREA (ha)	% OF TOTAL (%)
0	116,266	15.2
1-50	179,897	23.5
50.1-100	122,486	16.0
100.1-150	133,326	17.4
150.1-200	65,612	8.6
200.1-250	81,721	10.7
250.1-300	43,625	5.7
300.1-350	14,893	1.9
350.1-400	8,297	1.1
TOTAL	766,125	100.0

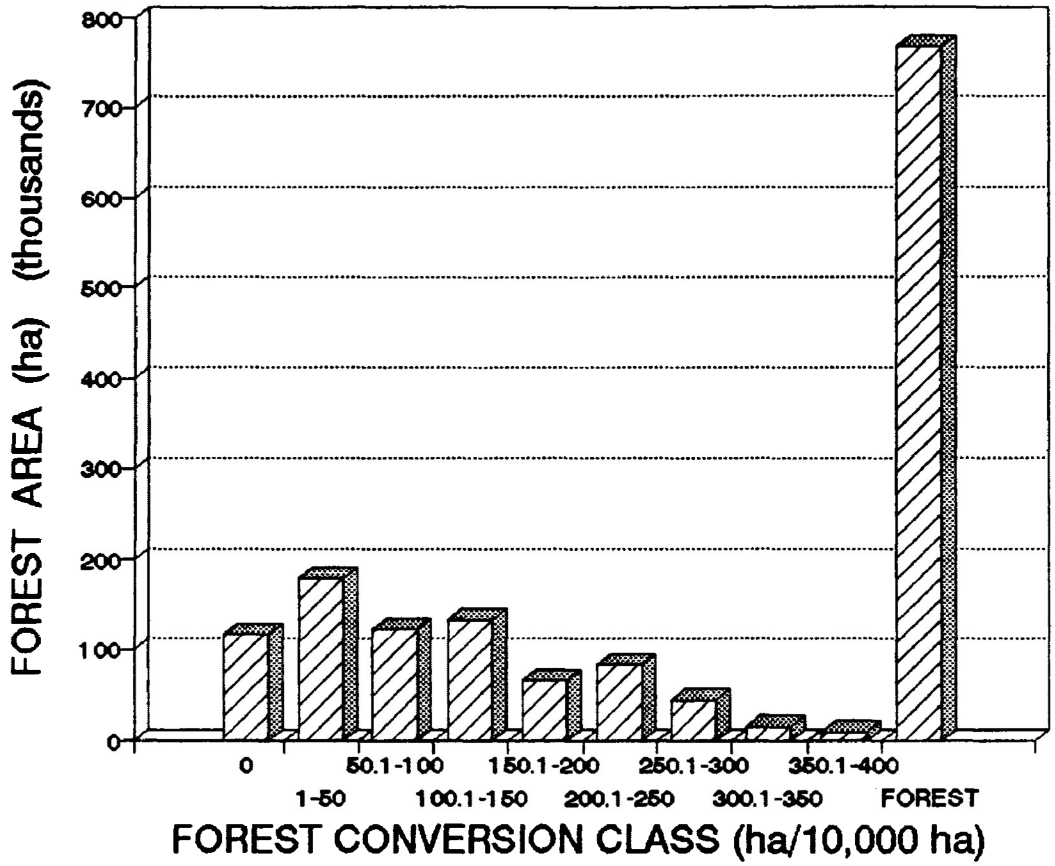


Figure 36 : Area within classes of forest area conversion by road clearances, for the Spruce River forest.

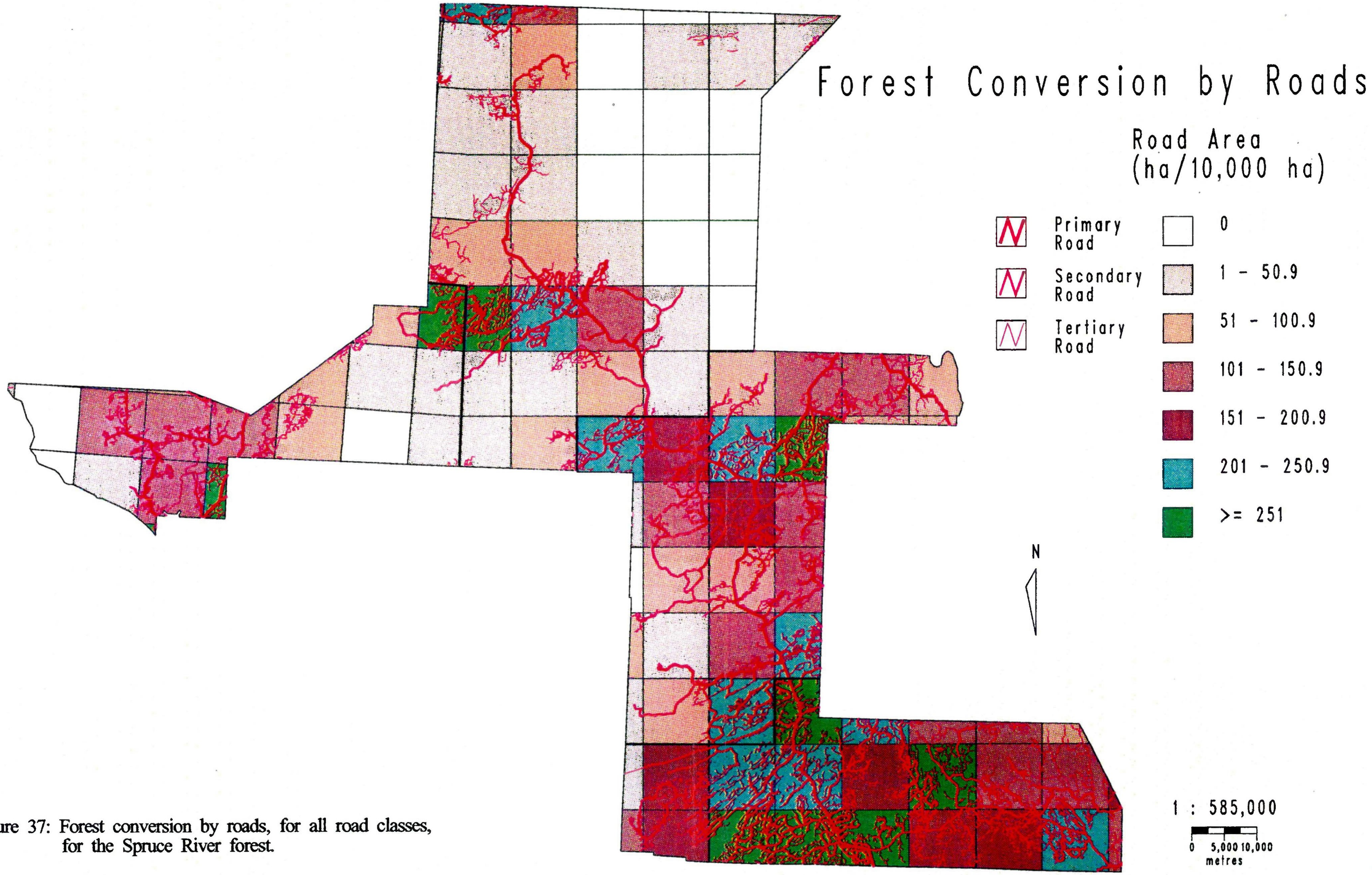


Figure 37: Forest conversion by roads, for all road classes, for the Spruce River forest.

FMU.

Interpretation and Evaluation

Zones of high forest conversion by roads correspond to zones of elevated net edge density and road density (indicators 10 and 12, respectively). Maximum target levels could be set for forest conversion by roads and landings classes (per 10,000 ha) for basemaps within a particular region, regions, or the entire FMU. These could be based on consideration for area- and human-sensitive wildlife species, and existence and wilderness values.

In this study, the area of landings was not included within this indicator since it was not available in the FMU database. This resulted in an under-estimation of forest conversion by possibly up to 4.6% (as cited above). Any reduction in the integrity of the road layer data will affect this indicator in a similar way as in "Road Density" (indicator 12).

CHAPTER 5: RECOMMENDATIONS FOR OPERATIONAL USE OF SUSTAINABILITY INDICATORS IN FOREST PLANNING

PUBLIC INVOLVEMENT

The role of the public in forest decision-making is expanding and becoming stronger (Higgelke and Duinker 1993; Johnson and Duinker 1993). An example is the recent requirement by the Ontario Environmental Assessment Board (Koven and Martel 1994) for a local citizens' committee to be associated with the development of each timber-management plan for Crown forests. Given this situation, it will be vital that the public both accepts and understands the indicators used by planners to gauge forest sustainability. There is no better way to gain such acceptance and understanding than to involve members of the public in the development and use of indicators.

Choosing Indicators

An obvious early task for a local citizens' committee is to work with the forest planning team in determining what indicators of forest sustainability to use and how to apply them. Decision-making around indicators can be a sensitive issue, since they will ultimately relate to the goals set for a forest and thus have political implications. Right from the start, participants should try to include a balanced spectrum of indicators related to economic, environmental and social values, consistent with principles of sustainability. Emphasis might be placed on regionally important as well as rare or threatened forest features. Important participants in achieving the right balance between local and provincial interests required for sustainability, are regional and provincial groups.

Indicators which encompass a number of human values and multiple essential ecosystem features also make good initial choices. For instance, the road density indicator also provides information about remoteness, amount of edge, fragmentation, and patch size distribution. As an added advantage, road density is relatively easy to measure.

Technical feasibility and ease of application of indicators are, of course, overriding concerns. Once some kind of priority list is established, participants can choose from the list until technical capacities for indicator analysis are reached. It will be necessary for all participants to work diligently yet patiently with each other as the rationale, meaning and possible interpretations for each indicator are worked out.

Choosing Display Formats

Participants also need to determine the best ways for indicators to be displayed. Several formats for representing data (e.g., tables, histograms, and maps) are best used in concert, each contributing complementary types and levels of information. Each format has strengths and weaknesses which need to be considered when participants design for public comprehension of forest-sustainability indicators. Histograms provide an initial overview of the data. They reveal patterns in the data often not discernable from simple tables of numbers. Histograms allow a comparison and summary of data in a customized format to satisfy some desired purpose. When more detailed data are required than provided by a histogram, the raw data contained in tables can be consulted directly.

Once non-spatial information has been extracted from the data, then spatial relationships can be investigated through maps. When maps serve as output for spatial and temporal models, they provide another dimension of information, such as the shapes and juxtaposition of forest cover types. Map outputs are far more useful than tables and figures when informing and involving the public in planning. The full visual potential of GIS should be put to use in framing spatial data in numerous combinations in map form.

FOREST INVENTORY DATABASE

Several problems will be faced by forest planners when it comes to using forest inventory databases for indications of forest sustainability. The basic data may be difficult to work with because: (a) they are not mapped digitally; (b) they are old and not updated; (c) they are timber-oriented and narrow in scope; and (d) their forest stand polygons and database units may not be ecologically meaningful. Each of these challenges are examined in turn.

Digital Mapping

Many indicators of forest sustainability require spatial analysis for the preparation of results. Detailed spatial analysis of forest data is impossible without digital data stored in a GIS. Unfortunately, many Crown forests in Ontario still do not have inventory databases mapped digitally. Thus, forest-sustainability indicators in these situations must be restricted to variables that can be analyzed aspatially using digital forest-inventory ledgers. This may be frustrating to planners, but should not deter them from developing and applying indicators of forest sustainability. Many strong indicators (e.g., forest age-class diversity) do not require digital maps, and sound efforts at ecosystem management can be made nonetheless (e.g., Ontario's White River Forest, as reported in Wedeles et al., 1994).

Old Data

The current system of providing forest resource inventories (FRIs) for Crown lands in Ontario relies on interpretation of aerial photography taken at roughly 20-year intervals. With time, a photo-interpreted inventory database becomes out of date, mainly because natural events and forest-management operations take place after the photos were taken. If these events and operations are not routinely recorded into the database, it becomes an error-riddled representation of the current state of the forest.

Updating of a forest inventory database requires considerable time and effort, both scarce commodities these days. Forest planners may be tempted to put their limited resources into updating the database mainly in line with information needs for timber operations, particularly harvest and regeneration. This may mean that updating critical to proper consideration of forest sustainability through the use of a variety of indicators does not occur, and the database becomes unsuitable for this use. Planning teams anxious to use forest-sustainability indicators will need to address this problem of inventory database updating. Satellite imagery hold great promise as an efficient data source for inventory updating.

Timber-oriented Data

The forest-resource inventory for Crown land in Ontario is a timber database (Kapron 1994; Watt 1994). Stands are delineated from aerial photos based mainly on overstorey composition, and data provided in inventory ledgers are oriented toward obtaining and maintaining an industrial wood supply. Much information by way of indications of forest sustainability can be gleaned from FRI datasets by analyzing them in different ways. Still, many sustainability concerns cannot be addressed effectively, if at all, using indicators derived from FRI. Examples include biodiversity of stand understories, nutrient status of forest ecosystems, and movement of soil materials into water courses.

Thus, while the FRI can be used in forest planning beyond merely a timber-oriented function, other datasets are required for many sustainability concerns. Thankfully, many forests in Ontario have additional resource-oriented datasets, although not all are digitally mapped. Of particular significance is the digital Ontario

Basic Map series, which, among other things, includes the very useful mapping of elevations. Other sources of useful mapped data include geologic, geomorphologic, edaphic and land capability maps. The more useful data that can be assembled for the analysis of a forest's sustainability, the better. FRI is a good start, but much more is desirable.

Ecological Meaningfulness of Forest Stand Polygons and Database Units

FRI datasets delineate forest polygons mainly on the basis of overstorey composition. Ecological sustainability of forest ecosystems may be quite inadequately judged when a forest landscape is partitioned on the basis of tree cover. Other variables, such as understorey composition and soils, are vitally important. Much of the work in indicator development, testing and use, as the present study attests, will focus on determining new boundaries for forest polygons based on non-timber considerations.

An additional problem relates to separate digital datasets for each mapsheet in the FRI. This may not matter much for timber planning, but many spatially oriented sustainability indicators require that all mapped boundaries that have no correpondence to ecosystem conditions in the field (e.g., mapsheet boundaries) be removed or otherwise remedied.

Thirdly, FMU's and their digital databases are usually bounded by administrative borders as opposed to ecologically based ones. In the long term, the goal at the provincial level should be to re-design FMU's, and subsequently their databases, on an ecological basis. In the interim, planners should include adjacent areas within the same ecological region in their analysis.

ANALYTICAL RESOURCES AND PROTOCOLS

Analysts

Development, testing and application of indicators of forest sustainability requires a major investment in human resources. The technical work can be done either by a planner competent in GIS use, or by a team including a planner and a GIS technician/analyst. In this project, a two-person team (forest planner and GIS analyst) used ca. one month of time to develop, test, analyze and display each indicator. Of course, once planners become familiar with the whole idea of forest-sustainability indicators and get their datasets and algorithms in place, recurring use of the indicators will be much less time-consuming.

Computational Resources

This project was accomplished using a combination of workstation and personal computers. All GIS work was performed on workstations, while manipulation of output datasets for tabular and graphic display was done on personal computers. Clearly, because indicator development and use are based on detailed quantitative and spatial analyses, computer hardware and software needs are substantial. This will be less and less a constraint as time goes by - computing power will increase exponentially while prices remain affordable.

Vector vs. Raster

The decision to use either a raster or vector GIS format for a given indicator is based on several criteria. A vector format is suited to linear measures, and has good display qualities, but its demand on computing power and capacity for large operations can be a constraint. Raster format has the advantage of computational efficiency, but it introduces error for linear features and polygon boundaries, especially if the raster resolution is coarse. Also its display qualities can be poor, and smoothing operations introduce additional error. Raster may be the appropriate format for the largest GIS operations at the whole-forest level, where vector format is too cumbersome computationally.

SOME FINAL CAUTIONS ON THE USE OF INDICATORS

Indicator results for the Spruce River Forest, as reported above, are only as good as the data and assumptions that were used to calculate them. While one may legitimately challenge their accuracy, the indicators do incorporate the best data available for the forest. The assumptions associated with indicators should always be included with any report on monitoring activities. The use of indicators can be dangerous if data are so poor, or are taken out of context, so as to give a significantly distorted picture of the true state of the forest. This should strengthen everyone's resolve to improve indicator formulation and data collection (forest inventory).

Each indicator focusses on a specific trait of the forest, and frames the forest in a particular manner. Each indicator must be interpreted in the context of a suite of indicators, and other information known about the forest, as an indicator on its own only shows a limited view of the forest. It is vital to challenge the suite of indicators, continually incorporating new data and understanding as they become available, as the suite in current use is but a model, only one interpretation of ecosystem features.

CHAPTER 6: CONCLUSIONS

It is important to be reminded of this project's objectives. My aim was to explore the little-known territory of how to gauge management progress in moving toward forest sustainability. I set out to identify, define and try out a range of biophysical measures related to forest condition. The project did not directly evaluate economic uses of forest resources, for which measures and analytical procedures are relatively well developed. I argued for the need to move from concepts through principles to quantitative measures; forest sustainability will remain eternally elusive unless measures are found to tell whether it is being realized on the ground.

If we are to take the concept of forest sustainability seriously, it will be necessary to develop and apply relevant indicators in an explicitly adaptive approach to forest management. This study has revealed some important facets of such work. Indicator development and application is a challenging task that requires much time, energy, creativity, data, and analytical resources. While the project was completed in an academic environment (although still with time pressures associated with depleting budgets and filling agendas), real-world application will occur in the planning rooms of forest managers, and the meeting halls of local citizens' committees. These people, when developing a forest plan, will be under budgetary and time pressures at least equal to this project's. It will be very important to be, at once, both aggressive about using indicators to demonstrate progress toward forest sustainability, and modest with respect to what can realistically be achieved given the constraints at hand.

Indicator development and use will clearly require more effort in forest-management planning, and thus more money (for improved data, for analyzing indicators, etc). However, if one or two forest-sustainability indicators could be developed and analyzed in the first round of planning, and one or two new ones each subsequent round, for each forest, strong progress will be made. Given that there are today many forest management units in Ontario with spatially digital forest inventories, this would mean that within ten years, twenty exercises of application of two to four spatially explicit sustainability indicators could have been completed. If these exercises are implemented with strong attention to learning and subsequent sharing of experiences, forest planning in Ontario will indeed be enriched.

In any exploratory endeavour with limited resources, one needs to reckon the tensions between wanting to be comprehensive on one hand and deeply analytical on the other. At some risk, a wide range of indicators were explored, sacrificing the depth to which analysis with each one could be taken. Nor was the full range of desired indicators developed in detail. Some indicators which may be a priority to monitor for sustainability, such as soil-site productivity and water quality, were dropped early in the project since digital data do not exist presently, or methods and resources are not available to capture data over expansive forest tracts. The slate of indicators, described and demonstrated in application above, are presented in the hope that analysts will either try them out themselves, or at least be motivated to create better ones for their own situations. This slate, I cannot emphasize enough, is tentative and preliminary. If the indicators must be abandoned in favour of more meaningful ones, then perhaps they have served a useful purpose as strawmen in the early debates on what indicators should be used to gauge forest sustainability.

The process of developing and testing indicators was certainly an iterative one. Initially, a series of quantitative measures were put on the table for examination and discussion. Each measure was evaluated by asking whether it was implementable, and could provide useful information in judging progress toward achieving forest sustainability. If the indicator was not then rejected, enhancements were made. There was a continual process of trial, evaluation, and enhancement, until the indicator satisfied expectations, within data constraints.

In developing the indicators described here, the forest of interest were the managed boreal forests of Ontario. The degree to which the indicators might be useful and applicable in other forest types, such as the Great-Lakes/St. Lawrence forests of Ontario, was not investigated. However, most if not all indicators explored should have applicability in other managed forests, at least at the conceptual level. Particulars on how each indicator is analyzed across space and through time would need to be specially designed for each forest application.

As in setting directions for management and policy of public forest land (Johnson and Duinker 1993; Higgelke and Duinker 1993), it is also important to have effective public participation in the kind of research undertaken here into indicators of forest sustainability. Based on this research, stakeholders, interest groups, and the general public need more opportunity to learn about the latest developments in the exploration of forest sustainability. About half of the groups sending a representative to the indicators workshop stated that they attended mainly to learn more about forest sustainability and its indicators. Public involvement in information sessions and working groups is critical to improving the understanding and adoption of the ecocentric perspective embodied in the type of forest sustainability indicators proposed here. However, convenors' expectations for interest-group involvement must be reasonable. Groups are often interested in participating (as the response rates to requests for input demonstrate). It is critical to bring many more of people's values that are related to forest sustainability to the stage of tested indicators.

Indicator development is hampered by serious deficiencies in biophysical and socio-economic understanding of boreal forests. The following are key topics for future research for more-secure indicators:

(a) landscape-level habitat requirements for boreal fauna, particularly for forest-interior and area-sensitive species with large home ranges;

(b) ecological processes and functions (most ecological information is related to pattern and structure of ecosystem components);

(c) impacts of human activities on forest biota;

(d) benefits of forest attributes to people, and how people value those attributes (e.g. the importance of wilderness characteristics such as remoteness and naturalness);

(e) baseline range of conditions for representative natural forest ecosystems; and

(f) scale of ecological context in time and space dimensions.

It is imperative to test the indicators on a range of forecasts for the future structure of a forest under alternative management strategies. This is the only way that indicators can be useful in forest-management decision-making. There is at least some research-based experience in forecasting non-timber values in response to management strategies for specific Ontario forests (e.g., McCallum 1993; Higgelke 1994), but operational experience in real planning exercises is desperately needed.

Achievement of forest sustainability is the paramount obligation for forest managers worldwide. The new Policy Framework for Sustainable Forests (OMNR 1994) requires it, as will the new legislation (Crown Forest Sustainability Act) replacing the Crown Timber Act. Current national and international initiatives dedicated to improving forest management (e.g. Anonymous 1992; Schlaepfer 1993) also focus on the concept of forest sustainability. Forest managers will have to demonstrate to the public, especially for public forest land, that they know how to achieve forest sustainability, and that they can demonstrate such achievement. Indicators of forest sustainability are thus vital tools for gauging progress. Since managing for forest sustainability involves human intervention in complex ecosystems, a broad suite of indicators is required to explore the multiple facets of the sustainability crystal. We must view forest sustainability as one views a complex crystal, through many indicator facets in order to capture its complexities. Sustainability cannot be seen in its entirity by viewing just one or a few facets. Alternatively, forest sustainability can be envisioned as a large mansion, and each indicator or sub-set of indicators, as a window, providing a different view of the inner dimensions. The entire interior cannot be seen through just a few windows. Some corners of rooms may not be seen at all. In some cases we may be able to punch new windows through to allow illumination. However, some rooms or aspects of sustainability, may never see the light of day.

I have offered here just one small set of indicator candidates. Some may be found useful in real planning situations, others may not. Regardless, forest planners and the public will have to develop and apply useful and meaningful indicators. Hopefully this research provides both a first approximation for some forest-sustainability indicators, and also identifies some potential pitfalls that others may well want to avoid.

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APPENDICES

APPENDIX 1: ONTARIO FOREST RESOURCES INVENTORY SYSTEM AND FOREST REPORTING BY THE OMNR

Ontario Forest Resources Inventory (FRI)

Inventory of forest stands in the province, reporting on a stand basis: land area, tree species composition, height, diameter, stocking, site class

- Stand volumes calculated from normal yield tables
- Timber management plans for each FMU contain an inventory summary - FMU summaries are aggregated to provide regional and provincial summaries - The first provincial summary report was 1963
- Each FMU is re-inventoried every 20 years
- The inventory is efficiently updated with the Forest Resources Data Entry System (FRIDES) computer software

Current program for entry of FRI onto GIS provincially

Dixon Report (Dixon, 1982)

A report on the performance of forest management under the Forest Production Policy implementation policy of February, 1973 for the period 1973-4 to 1980-81. A comparison of planned and actual work done. Reported mostly silvicultural operations: regeneration, tending, site preparation, and marking.

The Forest Resources of Ontario 1986 (OMNR, 1986)

- An historic background of silvicultural improvement to date.
- Historic data on roundwood production and wood harvest
- A summary of timely data on the composition of Ontario's forest by region from FRI data:
  - productive, non-productive, and non-forested areas
  - wood volume of Crown, parks, and private lands
  - age class, ownership, species composition as percentages of growing stock volume

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APPENDIX 2: A COMPREHENSIVE MATRIX OF INDICATORS OF FOREST SUSTAINABILITY

Template for Indicator Matrix

A 1	B 1	C 1
A 2	B 2	

APPENDIX 2. PAGE A1: INDICATORS OF FOREST SUSTAINABILITY

	VALUES	FOREST ECOSYSTEM ATTRIBUTE			
		A	B	C	D
		Wildlife Pop.	Habitat	Access	Forest Ecosystem Diversity
1	Recreation/Tourism -Consumptive -Non-Wilderness ie. hunting, fishing	• survey/census of: - game pop. - fish pop.	• suitability or carrying capacity (HSM's) • dist. of waterway buffer widths ie. total length or %/buffer width class	• length of road/unit area • waterway access points/unit area, water body, or waterway	
2	Recreation/Tourism -Consumptive -Wilderness ie. hunting, fishing	see A1	see B1	• area beyond a threshold distance from access • dist. of all ha's X distance from road (by road class)	
3	Recreation / Tourism -Non-Consumptive -Non-Wilderness			see C1	
4i	Recreation / Tourism -Non-Consumptive -Wilderness • no timber mgmt.			see C2	• ecosystem diversity (eg. stand type diversity, age class diversity incl. NSR [1] lands, wildlife diversity) • % land area in old growth [2]
4ii	• if timber mgmt.			see C2	see D4i
5i	Market • fur	• fur-bearer pop. estimates	see B1		• % land area in old growth • effective area old growth • max distance between patches of old growth • size of contiguous areas of old growth
5ii	• timber				• tree species diversity
6i	Subsistence Use - Traditional Native • hunting, fishing	see A1	see B1	see C1	
6ii	• trapping (marten, beaver, rabbit, lynx)	see A5i	see B1		see D5i
6iii	• gathering (berries, rice, mushrooms)		• suitable for wild rice (water levels)		• biodiversity/ecosystem diversity
6iv	Medicinal				see D6iii

1 Not Satisfactorally Regenerated
2 mature and old forest are included within old growth

APPENDIX 2 (cont.). PAGE B1: INDICATORS OF FOREST SUSTAINABILITY

	VALUES	FOREST ECOSYSTEM ATTRIBUTE					
		E	F	G	H	I	J
		Soil/Site	Water Quality	Waterways	Wilderness and Protected Areas	Carbon Storage and Flux	Forest Regeneration
1	Recreation -Consumptive -Non-Wilderness		• siltation • dissolved oxygen • heavy metals • acidity • pesticide levels				
2	Recreation -Consumptive -Wilderness		see F1				
3	Recreation -Non-Consumptive -Non-Wilderness		see F1	• kms canoe-navigable			
4i	Recreation -Non-Consumptive -Wilderness • no timber mgmt.		see F1	see G3	• area in wilderness grades - as defined in C2		
4ii	• if timber mgmt.		see F1	• see G3 • dist. of buffer widths ie. total length or %/buffer width class	see H4i		
5i	Market • fur						
5ii	• timber	• nutrient storage • buffering cap. to acidity • soil moisture regime • microbe diversity • soil structure (bulk dens.) • "O" horizon integrity • soil toxicity					• % productive forest land area NSR • % change in productive forest land area NSR • natural regeneration capability
6i	Subsistence Use - Traditional Native • hunting, fishing		see F1				
6ii	• trapping (marten, beaver, rabbit, lynx)						
6iii	• gathering (berries, rice, mushrooms)	see E5ii	• suitable for wild rice				
6iv	Medicinal						

APPENDIX 2 (cont.). PAGE C1: INDICATORS OF FOREST SUSTAINABILITY

	VALUES	FOREST ECOSYSTEM ATTRIBUTE				
		K	L	M	N	O
		Timber Supply	Timber Accessibility	Timber Quality		
1	Recreation -Consumptive -Non-Wilderness					
2	Recreation -Consumptive -Wilderness					
3	Recreation -Non-Consumptive -Non-Wilderness					
4i	Recreation -Non-Consumptive -Wilderness • no timber management					
4ii	• if timber management					
5i	Market • fur					
5ii	• timber	• growing stock volume/unit area • ratio of actual/potential harvest level (annual long run sustained yield by species) • area dist. of site and stand type	• distribution of haul distance X volume	• % defective timber (cull)		
6i	Subsistence Use - Traditional Native • hunting, fishing					
6ii	• trapping (marten, beaver, rabbit, lynx)					
6iii	• gathering (berries, rice, mushrooms)					
6iv	Medicinal					

APPENDIX 2 (cont.). PAGE A2: INDICATORS OF FOREST SUSTAINABILITY

	VALUES	FOREST ECOSYSTEM ATTRIBUTE			
		A	B	C	D
		Wildlife Pop.	Habitat	Access	Forest Ecosystem Diversity
7	Aesthetic/Scenic				• ecosystem diversity • % landscape in old growth • degree of natural appearance of harvest edges
8	Existence	• old growth and endangered wildlife species presence/ pop./distribution	• suitability or carrying capacity for old growth and endangered wildlife species (HSMs)		• biodiversity/ecosystem diversity • heterogeneity - stand type diversity, age class diversity • fragmentation - stand size dist. • area forest interior - low edge:area ratio • area forest type conversion
9	Option	see A8	see B8		see D8
10	Bequest	see A8	see B8		see D8
11	Spiritual/Ceremonial	see A8	see B8		• biodiversity/ecosystem diversity • % land area in old growth • habitats for wildlife biodiversity
12	Knowledge (education, scientific/research)	see A8	see B8		see D8
13	Heritage (Cultural) - Natural	see A8	see B8		see D8
14	Therapeutic /Character Building				see D8
15	Ecological Functioning	• see A8 • survey/census of: - other wildl. pop.	• see B8 • distribution of waterway buffer widths ie. total length or %/buffer width class	• see C2 • length of road/unit area	see D8

APPENDIX 2 (cont.). PAGE B2: INDICATORS OF FOREST SUSTAINABILITY

	VALUES	FOREST ECOSYSTEM ATTRIBUTE					
		E	F	G	H	I	J
		Soil/Site	Water Quality	Waterways	Wilderness and Protected Areas	Carbon Storage and Flux	Forest Regeneration
7	Aesthetic			• distribution of buffer widths in aesthetically sensitive areas ie. total distance or %/ buffer width class			
8	Existence		see F1		• area in wilderness grades - as defined in C2, D8 • representation of unaltered ecosystem types		
9	Option		see F1		see H8		
10	Bequest		see F1		see H8		
11	Spiritual/Ceremonial		see F1		see H8		
12	Knowledge (education, scientific/research)		see F1		see H8		
13	Heritage (Cultural) - Natural		see F1	• dist. of buffer widths	see H8		
14	Therapeutic /Character Building		see F1	• see G13	see H8		
15	Ecological Functioning	see E5ii	see F1	• disruptions to water flow eg. dams • dist. of buffer widths	see H8	• biomass • % change in biomass	see J5ii

APPENDIX 3: DATA TABLES

Appendix 3.1: Forest stand size class distribution for the Spruce River forest.

STAND SIZE CLASS (ha)	MID-POINT (ha)	NUMBER OF STANDS	PERCENT OF STANDS (%)	AREA (ha)	% OF TOTAL AREA (%)	CUM. % AREA (%)
0 - 19.9	10	13,655	63.297	111,551.3	17.6	17.6
20 - 39.9	30	4,218	19.552	118,164.6	18.7	36.3
40 - 59.9	50	1,553	7.199	75,600.1	11.9	48.2
60 - 79.9	70	834	3.866	57,418.1	9.1	57.3
80 - 99.9	90	437	2.026	38,966.1	6.2	63.5
100 - 119.9	110	260	1.205	28,359.8	4.5	68.0
120 - 139.9	130	161	0.746	20,808.4	3.3	71.2
140 - 159.9	150	97	0.450	14,420.9	2.3	73.5
160 - 179.9	170	70	0.324	11,863.3	1.9	75.4
180 - 199.9	190	50	0.232	9,440.7	1.5	76.9
200 - 219.9	210	35	0.162	7,263.9	1.1	78.0
220 - 239.9	230	30	0.139	6,935.8	1.1	79.1
240 - 259.9	250	22	0.102	5,507.4	0.9	80.0
260 - 279.9	270	26	0.121	7,042.1	1.1	81.1
280 - 299.9	290	19	0.088	5,477.7	0.9	82.0
300 - 319.9	310	12	0.056	3,737.8	0.6	82.6
320 - 339.9	330	11	0.051	3,597.2	0.6	83.1
340 - 359.9	350	6	0.028	2,113.7	0.3	83.5
360 - 379.9	370	11	0.051	4,047.4	0.6	84.1
380 - 399.9	390	6	0.028	2,341.6	0.4	84.5
400 - 419.9	410	3	0.014	1,226.9	0.2	84.7
420 - 439.9	430	3	0.014	1,296.7	0.2	84.9
440 - 459.9	450	5	0.023	2,239.0	0.4	85.2
460 - 479.9	470	4	0.019	1,887.5	0.3	85.5
480 - 499.9	490	7	0.032	3,415.2	0.5	86.1
500 - 519.9	510	2	0.009	1,019.5	0.2	86.2
520 - 539.9	530	0	0.000	0.0	0.0	86.2
540 - 559.9	550	1	0.005	546.9	0.1	86.3
560 - 579.9	570	1	0.005	561.6	0.1	86.4
580 - 599.9	590	0	0.000	0.0	0.0	86.4
600 - 619.9	610	2	0.009	1,233.9	0.2	86.6
620 - 639.9	630	3	0.014	1,884.3	0.3	86.9
640 - 659.9	650	0	0.000	0.0	0.0	86.9
660 - 679.9	670	2	0.009	1,358.2	0.2	87.1
680 - 699.9	690	0	0.000	0.0	0.0	87.1
700 - 719.9	710	1	0.005	709.7	0.1	87.2
720 - 739.9	730	2	0.009	1,460.9	0.2	87.5
740 - 759.9	750	2	0.009	1,480.8	0.2	87.7
760 - 779.9	770	1	0.005	771.5	0.1	87.8
780 - 799.9	790	2	0.009	1,572.5	0.2	88.1
800 - 819.9	810	0	0.000	0.0	0.0	88.1
820 - 839.9	830	0	0.000	0.0	0.0	88.1
840 - 859.9	850	0	0.000	0.0	0.0	88.1
860 - 879.9	870	1	0.005	875.4	0.1	88.2
880 - 899.9	890	2	0.009	1,795.3	0.3	88.5
900 - 919.9	910	1	0.005	907.0	0.1	88.6
920 - 939.9	930	1	0.005	920.9	0.1	88.8
940 - 959.9	950	0	0.000	0.0	0.0	88.8
960 - 979.9	970	0	0.000	0.0	0.0	88.8
980 - 999.9	990	2	0.009	1,981.9	0.3	89.1
1000 - 1019.9	1,010	1	0.005	1,017.6	0.2	89.2
1280 - 1299.9	1,290	1	0.005	1,295.3	0.2	89.5
1740 - 1759.9	1,750	1	0.005	1,740.5	0.3	89.7
2000 - 2019.9	2,010	1	0.005	2,014.0	0.3	90.0
2560 - 2579.9	2,570	1	0.005	2,561.8	0.4	90.5
3060 - 3079.9	3,070	1	0.005	3,079.0	0.5	90.9
3480 - 3499.9	3,490	1	0.005	3,480.3	0.5	91.5
3720 - 3739.9	3,730	1	0.005	3,726.4	0.6	92.1
4260 - 4279.9	4,270	1	0.005	4,263.3	0.7	92.8
4860 - 4879.9	4,870	1	0.005	4,861.5	0.8	93.5
10500 - 10519.9	10,510	1	0.005	10,516.8	1.7	95.2
30500 - 30519.9	30,510	1	0.005	30,500.3	4.8	100.0
TOTAL	NA	21,573	100	632,860.3	100	NA

Appendix 3.2: Size class distribution for forest patchwork, including roads as patch boundaries, for region 3 of the Spruce River forest.

PATCH SIZE CLASS (ha)	SIZE CLASS MID-POINT (ha)	NUMBER OF PATCHES	PERCENT OF PATCHES (%)	AREA (ha)	% OF TOTAL AREA (%)
0 - 19.9	10	1792	76.09	10,719.7	6.8
20 - 39.9	30	247	10.49	6,907.7	4.4
40 - 59.9	50	75	3.19	3,739.3	2.4
60 - 79.9	70	46	1.95	3,172.9	2.0
80 - 99.9	90	38	1.61	3,356.6	2.1
100 - 119.9	110	15	0.64	1,667.0	1.1
120 - 139.9	130	20	0.85	2,586.9	1.6
140 - 159.9	150	17	0.72	2,522.2	1.6
160 - 179.9	170	8	0.34	1,350.5	0.9
180 - 199.9	190	5	0.21	934.2	0.6
200 - 219.9	210	4	0.17	833.9	0.5
220 - 239.9	230	6	0.26	1,392.3	0.9
240 - 259.9	250	8	0.34	2,022.9	1.3
260 - 279.9	270	4	0.17	1,070.1	0.7
280 - 299.9	290	6	0.26	1,751.0	1.1
300 - 319.9	310	6	0.26	1,843.0	1.2
320 - 339.9	330	4	0.17	1,293.0	0.8
340 - 359.9	350	6	0.26	2,118.4	1.3
360 - 379.9	370	2	0.09	739.1	0.5
380 - 399.9	390	3	0.13	1,171.4	0.7
400 - 419.9	410	1	0.04	408.9	0.3
420 - 439.9	430	1	0.04	425.2	0.3
440 - 459.9	450	0	0.00	0.0	0.0
460 - 479.9	470	2	0.09	938.9	0.6
480 - 499.9	490	2	0.09	993.2	0.6
500 - 519.9	510	2	0.09	1,017.4	0.6
520 - 539.9	530	1	0.04	523.0	0.3
540 - 559.9	550	1	0.04	545.5	0.3
560 - 579.9	570	1	0.04	571.9	0.4
580 - 599.9	590	3	0.13	1,774.3	1.1
600 - 619.9	610	0	0.00	0.0	0.0
620 - 639.9	630	0	0.00	0.0	0.0
640 - 659.9	650	1	0.04	655.4	0.4
660 - 679.9	670	0	0.00	0.0	0.0
680 - 699.9	690	1	0.04	698.2	0.4
700 - 719.9	710	0	0.00	0.0	0.0
720 - 739.9	730	0	0.00	0.0	0.0
740 - 759.9	750	1	0.04	748.4	0.5
760 - 779.9	770	1	0.04	768.9	0.5
780 - 799.9	790	0	0.00	0.0	0.0
800 - 819.9	810	0	0.00	0.0	0.0
820 - 839.9	830	1	0.04	828.4	0.5
840 - 859.9	850	1	0.04	854.1	0.5
860 - 879.9	870	0	0.00	0.0	0.0
880 - 899.9	890	2	0.09	1,776.8	1.1
1020 - 1039.9	1030	1	0.04	1,035.1	0.7
1140 - 1159.9	1150	2	0.09	2,297.5	1.5
1160 - 1179.9	1170	1	0.04	1,179.5	0.7
1260 - 1279.9	1270	1	0.04	1,267.4	0.8
1400 - 1419.9	1410	1	0.04	1,403.5	0.9
1740 - 1759.9	1750	1	0.04	1,746.1	1.1
1860 - 1879.9	1870	1	0.04	1,872.1	1.2
2040 - 2059.9	2050	1	0.04	2,048.2	1.3
2100 - 2119.9	2110	1	0.04	2,115.4	1.3
2340 - 2359.9	2350	1	0.04	2,352.1	1.5
3620 - 3639.9	3630	1	0.04	3,627.5	2.3
4480 - 4499.9	4490	1	0.04	4,483.0	2.8
4520 - 4539.9	4530	1	0.04	4,530.4	2.9
5460 - 5479.9	5470	1	0.04	5,464.6	3.5
6060 - 6079.9	6070	1	0.04	6,076.5	3.8
6400 - 6419.9	6410	1	0.04	6,407.1	4.0
6920 - 6939.9	6930	1	0.04	6,934.2	4.4
11160 - 11179.9	11170	1	0.04	11,164.3	7.1
12360 - 12379.9	12370	1	0.04	12,366.4	7.8
15260 - 15279.9	15270	1	0.04	15,271.3	9.6
TOTAL	NA	2,355	100	158,362.7	100

Appendix 3.3: Patch size class distribution for > 40% conifer older forest, for Region 3 of the Spruce River forest.

PATCH SIZE CLASS (ha)	SIZE CLASS MID-POINT (ha)	NUMBER OF PATCHES	PERCENT OF PATCHES (%)	AREA (ha)	% OF TOTAL AREA (%)
0 - 19.9	10	684	67.19	4,273.9	5.2
20 - 39.9	30	120	11.79	3,501.8	4.3
40 - 59.9	50	40	3.93	1,944.5	2.4
60 - 79.9	70	31	3.05	2,141.6	2.6
80 - 99.9	90	15	1.47	1,334.7	1.6
100 - 119.9	110	17	1.67	1,916.5	2.3
120 - 139.9	130	12	1.18	1,556.6	1.9
140 - 159.9	150	11	1.08	1,638.9	2.0
160 - 179.9	170	11	1.08	1,826.5	2.2
180 - 199.9	190	4	0.39	773.1	0.9
200 - 219.9	210	3	0.30	635.0	0.8
220 - 239.9	230	3	0.30	688.8	0.8
240 - 259.9	250	6	0.59	1,465.4	1.8
260 - 279.9	270	3	0.30	798.5	1.0
280 - 299.9	290	6	0.59	1,757.3	2.1
300 - 319.9	310	1	0.10	317.5	0.4
320 - 339.9	330	1	0.10	329.8	0.4
340 - 359.9	350	4	0.39	1,410.8	1.7
360 - 379.9	370	1	0.10	366.6	0.4
380 - 399.9	390	2	0.20	781.6	1.0
400 - 419.9	410	2	0.20	811.8	1.0
420 - 439.9	430	2	0.20	861.3	1.1
440 - 459.9	450	1	0.10	444.3	0.5
460 - 479.9	470	0	0.00	0.0	0.0
480 - 499.9	490	6	0.59	2,948.9	3.6
500 - 519.9	510	0	0.00	0.0	0.0
520 - 539.9	530	2	0.20	1,048.7	1.3
540 - 559.9	550	1	0.10	551.1	0.7
560 - 579.9	570	3	0.30	1,708.9	2.1
580 - 599.9	590	0	0.00	0.0	0.0
600 - 619.9	610	2	0.20	1,223.1	1.5
620 - 639.9	630	0	0.00	0.0	0.0
640 - 659.9	650	2	0.20	1,292.5	1.6
660 - 679.9	670	0	0.00	0.0	0.0
680 - 699.9	690	0	0.00	0.0	0.0
700 - 719.9	710	1	0.10	718.4	0.9
720 - 739.9	730	0	0.00	0.0	0.0
740 - 759.9	750	1	0.10	748.2	0.9
760 - 779.9	770	2	0.20	1,556.9	1.9
780 - 799.9	790	0	0.00	0.0	0.0
800 - 819.9	810	0	0.00	0.0	0.0
820 - 839.9	830	0	0.00	0.0	0.0
840 - 859.9	850	0	0.00	0.0	0.0
860 - 879.9	870	1	0.10	876.9	1.1
880 - 899.9	890	0	0.00	0.0	0.0
900 - 919.9	910	2	0.20	1,821.3	2.2
920 - 939.9	930	0	0.00	0.0	0.0
940 - 959.9	950	1	0.10	948.6	1.2
960 - 979.9	970	1	0.10	965.4	1.2
1100 - 1119.9	1,110	2	0.20	2,222.6	2.7
1200 - 1219.9	1,210	1	0.10	1,205.8	1.5
1240 - 1259.9	1,250	1	0.10	1,240.7	1.5
1380 - 1399.9	1,390	1	0.10	1,392.4	1.7
1440 - 1459.9	1,450	1	0.10	1,452.2	1.8
2180 - 2199.9	2,190	1	0.10	2,199.7	2.7
2200 - 2219.9	2,210	1	0.10	2,208.8	2.7
2240 - 2259.9	2,250	1	0.10	2,256.7	2.8
3480 - 3499.9	3,490	1	0.10	3,480.4	4.2
4080 - 4099.9	4,090	1	0.10	4,099.9	5.0
4920 - 4939.9	4,930	1	0.10	4,920.1	6.0
7360 - 7379.9	7,370	1	0.10	7,369.8	9.0
TOTAL	NA	1,018	100	82,034.6	100

Appendix 3.4 (page 1 of 2): Edge length for edge types by basemap.

FOREST REGION	BASEMAP	EDGE LENGTH (km)					TOTAL *
		EDGE TYPE					
		HW/SW	HEIGHT	ROAD	COVER	STOCKING	
1	1	4.1	98.9	17.4	38.3	75.5	230.1
1	2	16.1	41.9	17.4	59.3	67.9	186.4
1	3	55.7	63.4	0.0	231.0	170.4	464.9
1	4	1.0	86.0	0.0	23.3	117.1	226.4
1	5	77.3	47.8	10.2	125.0	114.9	297.8
1	6	2.3	0.5	0.0	0.9	0.5	2.0
1	7	62.6	26.5	0.0	184.5	55.9	266.9
1	8	0.0	0.0	0.0	0.4	0.4	0.7
1	9	1.7	2.5	0.0	7.3	2.6	12.4
1	10	54.7	73.1	5.9	174.9	100.1	354.0
1	11	9.5	2.2	2.4	10.4	2.1	17.1
1	12	96.6	72.1	7.2	133.5	92.4	305.2
1	13	0.0	1.2	0.0	0.4	1.2	2.8
1	14	51.4	101.4	22.0	160.3	107.2	390.9
1	15	13.7	81.5	0.0	13.8	103.7	198.9
1	16	136.8	26.8	0.0	195.8	97.5	320.0
1	17	48.2	51.5	0.0	84.9	75.6	212.1
1	18	4.8	0.7	0.0	34.4	8.9	44.1
1	19	66.7	12.2	3.6	149.0	26.2	190.9
1	20	140.3	97.2	18.7	200.2	134.3	450.3
1	21	22.4	73.1	10.4	48.2	67.4	199.1
1	22	2.0	3.5	0.0	3.0	3.5	10.0
2	1	0.0	1.5	0.0	1.4	0.9	3.8
2	2	24.6	54.5	2.8	60.1	33.7	151.1
2	3	2.4	2.2	10.5	14.1	11.2	38.0
2	4	4.2	5.2	0.0	9.4	17.7	32.3
2	5	16.9	8.3	0.0	37.2	26.9	72.4
2	6	29.9	3.9	0.0	27.6	12.6	44.1
2	7	5.6	0.9	0.0	12.0	1.7	14.7
2	8	0.0	3.4	1.1	0.0	3.2	7.8
2	9	27.9	64.8	6.5	102.7	66.7	240.6
2	10	56.1	56.2	24.9	176.1	80.2	337.5
2	11	112.1	134.8	0.0	193.4	103.6	431.8
2	12	20.2	4.4	0.0	35.4	42.9	82.7
2	13	69.5	50.8	0.0	195.1	84.7	330.6
2	14	46.6	58.9	0.0	93.5	64.3	216.7
2	15	0.0	0.2	0.0	0.0	0.2	0.3
2	16	5.8	50.3	8.0	120.1	49.3	227.8
2	17	8.3	26.6	0.0	212.5	34.5	273.6
2	18	4.8	57.3	0.0	226.7	147.8	431.9
2	19	32.0	44.2	0.0	91.1	13.3	148.6
2	20	18.3	46.0	12.6	117.0	24.5	200.0
2	21	0.0	96.6	0.2	99.3	35.8	231.8
2	22	1.6	116.2	0.3	127.0	33.8	277.3
2	23	0.9	116.1	0.0	167.8	35.5	319.4
2	24	68.3	126.6	0.0	219.7	84.0	430.3
2	25	21.9	77.5	0.0	131.6	88.6	297.7
2	26	0.0	153.4	2.0	142.8	40.6	338.7
2	27	4.2	118.2	1.9	141.5	93.6	355.3
2	28	46.7	68.5	3.1	95.1	57.0	223.6
2	29	18.8	125.5	0.0	253.6	87.4	466.5
2	30	60.4	92.5	0.0	204.1	115.5	412.1
2	31	0.0	89.1	13.1	22.0	107.5	231.8
2	32	24.7	198.5	29.7	194.2	193.4	615.8
2	33	71.5	133.0	46.2	254.1	229.0	662.2
2	34	91.4	162.9	30.9	250.5	233.8	678.1
2	35	58.9	87.6	0.0	173.5	114.8	375.9
2	36	93.1	57.0	11.5	130.4	102.2	301.0
2	37	118.6	50.8	3.7	269.4	110.0	433.8
2	38	115.5	79.2	32.3	347.2	116.7	575.4

* Includes all edge types except HW/SW

Appendix 3.4 (page 2 of 2): Edge length for edge types by basemap.

FOREST REGION	BASEMAP	EDGE LENGTH (km) EDGE TYPE HW/SW	HEIGHT	ROAD	COVER	STOCKING	TOTAL *
2	39	245.1	60.0	12.2	290.2	103.2	465.7
2	40	69.2	66.8	0.0	133.2	97.9	297.9
2	41	28.2	59.1	10.6	197.7	126.2	393.5
2	42	0.0	0.2	0.0	0.0	0.2	0.4
2	43	0.0	1.4	0.2	0.2	1.8	3.6
3	1	1.8	0.6	0.0	2.1	0.8	3.5
3	2	108.5	196.1	8.3	205.1	225.2	634.7
3	3	22.1	160.6	24.0	98.1	199.5	482.1
3	4	90.0	80.5	10.6	96.7	118.4	306.2
3	5	28.5	146.8	15.9	76.5	201.7	440.8
3	6	0.0	0.0	0.0	0.0	0.0	0.0
3	7	0.0	0.0	0.0	0.6	0.1	0.7
3	8	0.0	19.5	1.3	7.3	25.4	53.6
3	9	0.5	0.5	0.1	0.7	0.9	2.2
3	10	15.5	169.4	21.5	101.3	204.6	496.9
3	11	26.4	236.8	27.3	132.6	249.1	645.7
3	12	7.0	308.2	28.6	78.6	304.2	719.6
3	13	2.7	215.4	29.2	92.6	198.9	536.1
3	14	6.2	17.4	3.0	7.6	15.5	43.6
3	15	192.1	160.1	24.4	228.1	205.5	618.1
3	16	40.4	2.4	0.0	48.6	11.1	62.1
3	17	172.4	253.0	12.4	212.6	270.0	748.0
3	18	83.6	141.1	4.1	142.9	132.0	420.0
3	19	97.0	113.7	3.4	117.4	123.8	358.3
3	20	42.6	7.7	0.0	43.9	14.1	65.7
3	21	285.3	111.7	50.2	264.6	156.2	582.7
3	22	242.8	140.4	14.1	253.0	170.0	577.4
3	23	163.6	120.7	12.1	277.1	145.6	555.5
3	24	238.8	58.6	18.5	374.3	94.3	545.7
3	25	45.8	26.1	0.4	77.1	36.3	139.8
3	26	21.1	129.3	7.4	52.2	146.8	335.7
3	27	69.6	5.7	6.5	93.2	11.2	116.6
3	28	166.7	56.2	33.2	256.9	109.0	455.3
3	29	39.6	231.1	36.5	118.3	222.9	608.8
3	30	0.2	0.9	0.1	0.2	1.3	2.5
3	31	0.1	1.2	0.0	0.6	0.5	2.3
3	32	0.0	0.0	0.0	0.0	0.6	0.6
4	1	22.3	163.3	9.9	97.0	144.7	414.8
4	2	0.0	2.1	0.5	1.0	2.1	5.7
4	3	39.7	107.0	14.6	57.6	95.9	275.0
4	4	35.6	40.3	5.5	47.5	51.9	145.1
4	5	11.0	47.9	0.0	10.7	59.5	118.1
4	6	31.3	1.4	0.0	27.1	6.9	35.4
4	7	57.1	157.3	18.2	211.2	153.3	540.0
4	8	123.2	125.9	11.2	169.7	142.8	449.7
4	9	147.3	85.0	23.9	126.9	89.3	325.1
4	10	60.2	247.5	4.5	131.8	251.5	635.3
4	11	67.7	21.2	2.9	115.4	36.3	175.8
4	12	109.2	246.8	17.7	163.8	208.5	636.8
4	13	172.1	212.5	35.2	174.1	195.0	616.7
4	14	171.3	144.2	26.1	209.0	163.1	542.5
4	15	5.1	13.2	0.8	3.0	5.2	22.2
4	16	107.4	140.5	3.1	167.2	128.1	438.8
4	17	87.4	218.5	29.8	124.0	179.2	551.6
4	18	95.0	153.2	24.5	135.4	177.1	490.2
4	19	30.0	19.9	6.3	37.3	28.9	92.4
4	20	87.1	119.1	2.6	127.7	123.2	372.6
4	21	86.7	204.5	20.7	159.2	211.5	595.8
4	22	138.3	186.1	17.1	169.0	160.4	532.6
4	23	153.3	155.0	27.0	158.8	117.1	457.8
4	24	28.7	8.1	4.8	14.1	11.6	38.6
TOTAL	NA	6,535.2	9,646.8	1,079.4	13,487.1	10,712.9	34,926.2

* Includes all edge types except HW/SW

Appendix 3.5 (page 1 of 2): Net edge length for edge type combinations, and net edge density by basemap.

FOREST REGION	BASEMAP	BASEMAP AREA (ha)	NET EDGE LENGTH (km) EDGE TYPE COMBINATION HT-STOCK	STOCK-RD	HT-RD	HT-STOCK-R	HT-STOCK-RD NET EDGE DENSITY (km/10,000 ha)
1	1	6,519.8	149.7	92.9	116.3	167.1	256.2
1	2	4,622.2	80.3	85.3	59.3	97.7	211.3
1	3	10,002.3	184.9	170.4	63.4	184.9	184.9
1	4	5,564.5	140.3	117.1	86.0	140.3	252.1
1	5	7,302.2	127.6	125.1	58.0	137.8	188.7
1	6	164.1	0.5	0.5	0.5	0.5	32.3
1	7	8,070.4	56.3	55.9	26.5	56.3	69.8
1	8	30.6	0.4	0.4	0.0	0.4	114.4
1	9	284.4	3.0	2.6	2.5	3.0	106.5
1	10	10,011.3	105.2	106.1	79.0	111.2	111.0
1	11	418.6	3.0	4.5	4.6	5.4	129.0
1	12	9,980.0	98.1	99.6	79.3	105.3	105.5
1	13	79.5	1.2	1.2	1.2	1.2	148.4
1	14	7,989.0	128.1	129.2	123.4	150.1	187.9
1	15	8,402.2	134.8	103.7	81.5	134.8	160.5
1	16	8,086.5	104.7	97.5	26.8	104.7	129.5
1	17	5,940.1	89.2	75.6	51.5	89.2	150.1
1	18	2,042.5	8.9	8.9	0.7	8.9	43.6
1	19	6,910.2	28.8	29.8	15.7	32.3	46.8
1	20	8,793.9	151.1	152.9	115.8	169.8	193.1
1	21	2,648.7	82.5	77.8	83.4	92.9	350.6
1	22	134.2	3.5	3.5	3.5	3.5	259.2
2	1	165.0	1.6	0.9	1.5	1.6	95.2
2	2	3,034.4	63.7	36.5	57.3	66.5	219.0
2	3	2,707.5	11.2	21.7	12.7	21.7	80.0
2	4	2,335.2	17.7	17.7	5.2	17.7	75.9
2	5	1,977.4	27.4	26.9	8.3	27.4	138.4
2	6	1,657.8	12.7	12.6	3.9	12.7	76.7
2	7	1,259.6	1.7	1.7	0.9	1.7	13.7
2	8	321.5	3.4	4.3	4.5	4.5	140.9
2	9	10,602.8	90.7	73.1	71.2	97.2	91.6
2	10	10,000.8	99.5	105.2	81.1	124.4	124.4
2	11	9,999.3	187.9	103.6	134.8	187.9	187.9
2	12	4,025.3	43.8	42.9	4.4	43.8	108.8
2	13	9,999.8	100.5	84.7	50.8	100.5	100.5
2	14	9,974.3	107.7	64.3	58.9	107.7	108.0
2	15	21.9	0.2	0.2	0.2	0.2	82.3
2	16	11,326.0	67.7	57.3	58.3	75.7	66.8
2	17	10,000.0	52.6	34.5	26.6	52.6	52.6
2	18	10,001.1	176.5	147.8	57.3	176.5	176.5
2	19	8,031.3	49.4	13.3	44.2	49.4	61.5
2	20	9,999.1	59.8	37.1	58.6	72.4	72.4
2	21	11,776.2	98.5	36.0	96.7	98.7	83.8
2	22	10,000.2	120.8	34.1	116.4	121.1	121.0
2	23	10,000.9	129.3	35.5	116.1	129.3	129.3
2	24	9,999.6	159.3	84.0	126.6	159.3	159.3
2	25	7,644.9	137.6	88.6	77.5	137.6	180.0
2	26	12,217.0	162.4	42.6	155.4	164.4	134.6
2	27	10,000.0	159.3	95.5	120.2	161.2	161.2
2	28	10,000.1	84.8	60.1	71.5	87.8	87.8
2	29	9,999.7	168.4	87.4	125.5	168.4	168.4
2	30	7,350.5	151.8	115.5	92.5	151.8	206.5
2	31	6,904.2	163.0	120.7	102.3	176.2	255.1
2	32	10,000.1	260.7	223.1	228.2	290.4	290.4
2	33	10,000.1	262.6	275.1	179.2	308.8	308.8
2	34	9,999.9	282.3	264.7	193.8	313.2	313.2
2	35	7,045.0	138.3	114.8	87.6	138.3	196.2
2	36	7,302.0	115.8	113.6	68.5	127.2	174.2
2	37	10,000.2	126.6	113.6	54.5	130.2	130.2
2	38	9,993.3	146.8	149.1	111.5	179.1	179.2

Appendix 3.5 (page 2 of 2): Net edge length for edge type combinations, and net edge density by basemap.

FOREST REGION	BASEMAP	BASEMAP AREA (ha)	NET EDGE LENGTH (km) EDGE TYPE COMBINATION HT-STOCK	STOCK-RD	HT-RD	HT-STOCK-R	HT-STOCK-RD NET EDGE DENSITY (km/10,000 ha)
2	39	9,944.4	120.9	115.5	72.3	133.2	133.9
2	40	5,941.1	120.6	97.9	66.8	120.6	203.0
2	41	8,094.3	146.2	136.8	69.7	156.8	193.7
2	42	9.9	0.2	0.2	0.2	0.2	191.2
2	43	68.9	2.6	2.1	1.6	2.9	415.0
3	1	55.7	0.8	0.8	0.6	0.8	138.3
3	2	9,998.2	264.4	233.5	204.4	272.7	272.8
3	3	9,807.9	228.9	223.5	184.5	252.8	257.8
3	4	6,605.7	139.2	129.0	91.1	149.8	226.7
3	5	9,536.6	220.4	217.5	162.7	236.2	247.7
3	6	0.1	0.0	0.0	0.0	0.0	0.0
3	7	6.7	0.1	0.1	0.0	0.1	88.9
3	8	1,177.9	27.7	26.7	20.8	29.0	246.3
3	9	23.4	1.0	1.0	0.6	1.1	479.4
3	10	8,749.3	227.0	226.1	190.9	248.5	284.0
3	11	9,931.0	300.5	276.3	264.1	327.8	330.1
3	12	10,000.4	366.3	332.8	336.8	394.9	394.9
3	13	7,936.5	242.9	228.1	244.7	272.2	342.9
3	14	970.3	22.6	18.6	20.5	25.6	264.2
3	15	10,000.1	231.5	229.9	184.5	256.0	256.0
3	16	1,700.4	11.1	11.1	2.4	11.1	65.1
3	17	9,999.6	319.0	282.4	265.4	331.4	331.4
3	18	7,452.3	188.6	136.1	145.1	192.7	258.6
3	19	7,140.4	140.1	127.2	117.1	143.4	200.9
3	20	1,964.5	14.3	14.1	7.7	14.3	72.9
3	21	9,999.5	168.6	206.4	161.9	218.8	218.8
3	22	10,000.1	180.3	184.1	154.5	194.4	194.4
3	23	10,000.1	164.7	157.7	132.8	176.8	176.8
3	24	9,999.8	97.5	112.8	77.1	116.0	116.0
3	25	2,087.6	36.8	36.7	26.5	37.2	178.0
3	26	6,810.8	165.2	154.2	136.7	172.7	253.5
3	27	2,459.2	11.7	17.7	12.3	18.2	74.1
3	28	10,009.8	111.8	142.2	89.4	145.0	144.9
3	29	9,961.5	288.7	259.5	267.6	325.3	326.5
3	30	36.4	1.3	1.4	1.0	1.4	392.5
3	31	30.2	1.2	0.5	1.2	1.2	394.3
3	32	3.2	0.6	0.6	0.0	0.6	1,894.5
4	1	7,915.4	208.0	154.6	173.2	217.9	275.3
4	2	38.6	2.1	2.6	2.5	2.6	671.1
4	3	3,772.4	135.7	110.5	121.6	150.4	398.6
4	4	3,494.3	61.7	57.4	45.8	67.2	192.3
4	5	3,237.1	60.0	59.5	47.9	60.0	185.4
4	6	1,923.3	7.6	6.9	1.4	7.6	39.4
4	7	10,000.6	189.4	171.5	175.4	207.6	207.6
4	8	9,999.3	208.6	154.1	137.1	219.8	219.8
4	9	9,186.3	114.2	113.2	108.9	138.1	150.3
4	10	9,999.6	308.8	256.0	252.0	313.3	313.3
4	11	2,928.1	41.8	39.2	24.2	44.8	152.9
4	12	9,969.4	285.9	226.2	264.5	303.6	304.5
4	13	9,999.3	266.5	230.2	247.7	301.7	301.7
4	14	9,986.4	213.4	189.3	170.4	239.5	239.8
4	15	462.0	13.6	6.1	14.0	14.4	312.3
4	16	7,986.0	155.3	131.2	143.6	158.4	198.3
4	17	8,235.1	244.5	209.0	248.3	274.3	333.0
4	18	8,751.0	207.0	201.6	177.6	231.4	264.4
4	19	2,068.7	31.4	35.2	26.2	37.7	182.0
4	20	7,179.7	150.4	125.8	121.7	153.0	213.0
4	21	8,460.9	235.6	232.2	225.2	256.3	303.0
4	22	9,067.9	214.4	177.5	203.2	231.5	255.3
4	23	9,356.6	195.7	144.1	182.0	222.7	238.0
4	24	1,921.5	15.2	16.4	12.9	20.0	103.9
TOTAL	NA	NA	742,329	13,763.9	11,792.3	10,726.1	14,843.2	NA

Appendix 3.6 (page 1 of 2): Density of roads for each road class by basemap.

FOREST REGION	BASEMAP	BASEMAP AREA (ha)	ROAD DENSITY (km/10,000 ha)			TOTAL
			PRIMARY	SECONDARY	TERTIARY	
1	1	6,519.8	0.0	77.1	118.3	195.4
1	2	4,622.2	0.0	21.5	18.4	39.8
1	3	10,002.3	0.0	0.3	7.6	7.9
1	4	5,564.5	0.0	0.0	62.2	62.2
1	5	7,302.2	0.0	7.7	3.1	10.8
1	6	164.1	0.0	0.0	40.7	40.7
1	7	8,070.4	0.0	0.0	0.0	0.0
1	8	30.6	0.0	0.0	0.0	0.0
1	9	284.4	0.0	0.0	41.7	41.7
1	10	10,011.3	2.7	11.1	82.2	96.0
1	11	418.6	0.0	36.9	14.5	51.4
1	12	9,980.0	4.1	9.2	91.3	104.6
1	13	79.5	0.0	0.0	99.4	99.4
1	14	7,989.0	8.8	14.1	88.6	111.5
1	15	8,402.2	0.0	0.0	74.8	74.8
1	16	8,086.5	0.0	0.0	0.0	0.0
1	17	5,940.1	0.0	0.0	4.5	4.5
1	18	2,042.5	0.0	0.0	0.0	0.0
1	19	6,910.2	0.0	3.1	15.6	18.6
1	20	8,793.9	11.6	7.8	105.3	124.7
1	21	2,648.7	33.7	0.0	175.5	209.1
1	22	134.2	0.0	0.0	270.9	270.9
2	1	165.0	0.0	41.3	109.9	151.2
2	2	3,034.4	0.0	46.9	130.9	177.7
2	3	2,707.5	0.0	20.2	68.5	88.7
2	4	2,335.2	0.0	0.0	0.0	0.0
2	5	1,977.4	0.0	0.0	0.0	0.0
2	6	1,657.8	0.0	0.0	0.0	0.0
2	7	1,259.6	0.0	0.0	40.2	40.2
2	8	321.5	0.0	17.1	39.9	57.0
2	9	10,602.8	0.0	8.7	21.8	30.5
2	10	10,000.8	0.0	12.6	29.8	42.4
2	11	9,999.3	0.0	0.0	9.2	9.2
2	12	4,025.3	0.0	0.0	31.1	31.1
2	13	9,999.8	0.0	0.0	0.0	0.0
2	14	9,974.3	0.0	0.0	11.0	11.0
2	15	21.9	0.0	0.0	0.0	0.0
2	16	11,326.0	0.0	3.6	38.2	41.8
2	17	10,000.0	0.0	0.0	0.0	0.0
2	18	10,001.1	0.0	0.0	0.0	0.0
2	19	8,031.3	0.0	0.0	0.0	0.0
2	20	9,999.1	11.4	0.9	17.1	29.3
2	21	11,776.2	3.0	1.3	26.4	30.7
2	22	10,000.2	7.7	0.1	25.2	33.0
2	23	10,000.9	0.0	0.0	0.0	0.0
2	24	9,999.6	0.0	0.0	0.0	0.0
2	25	7,644.9	0.0	0.0	0.0	0.0
2	26	12,217.0	5.2	6.3	64.2	75.6
2	27	10,000.0	6.8	17.7	41.8	66.3
2	28	10,000.1	0.0	16.7	13.4	30.1
2	29	9,999.7	0.0	0.0	0.0	0.0
2	30	7,350.5	0.0	0.0	0.0	0.0
2	31	6,904.2	3.8	60.6	178.0	242.3
2	32	10,000.1	11.3	51.2	112.9	175.5
2	33	10,000.1	17.6	21.5	24.0	63.1
2	34	9,999.9	3.9	13.2	0.9	18.0
2	35	7,045.0	0.0	0.0	0.0	0.0
2	36	7,302.0	0.8	12.8	5.0	18.6
2	37	10,000.2	0.0	1.8	18.6	20.4
2	38	9,993.3	5.0	13.2	28.2	46.3
2	39	9,944.4	5.6	1.1	5.1	11.8
2	40	5,941.1	0.0	0.0	10.0	10.0

Appendix 3.6 (page 2 of 2): Density of roads for each road class by basemap.

FOREST REGION	BASEMAP	BASEMAP AREA (ha)	ROAD DENSITY (km/10,000 ha) PRIMARY	SECONDARY	TERTIARY	TOTAL
2	41	8,094.3	0.0	10.1	37.2	47.2
2	42	9.9	0.0	77.3	103.0	180.4
2	43	68.9	7.1	55.0	39.1	101.2
3	1	55.7	0.0	0.0	44.9	44.9
3	2	9,998.2	0.0	18.4	31.5	49.9
3	3	9,807.9	11.7	8.7	67.1	87.5
3	4	6,605.7	13.9	0.0	52.3	66.2
3	5	9,536.6	7.0	9.4	108.1	124.5
3	6	0.1	0.0	0.0	0.0	0.0
3	7	6.7	0.0	0.0	0.0	0.0
3	8	1,177.9	0.0	10.4	61.1	71.4
3	9	23.4	0.0	60.8	229.3	290.0
3	10	8,749.3	0.0	37.6	126.6	164.3
3	11	9,931.0	13.6	31.3	94.5	139.4
3	12	10,000.4	13.6	26.7	123.2	163.5
3	13	7,936.5	8.4	47.4	174.6	230.4
3	14	970.3	16.7	0.0	33.6	50.3
3	15	10,000.1	0.0	36.3	61.1	97.4
3	16	1,700.4	0.0	0.0	8.4	8.4
3	17	9,999.6	11.5	26.8	93.6	131.9
3	18	7,452.3	0.0	18.4	90.4	108.8
3	19	7,140.4	0.0	23.7	90.2	113.9
3	20	1,964.5	0.0	0.0	0.0	0.0
3	21	9,999.5	0.0	33.5	2.2	35.7
3	22	10,000.1	0.0	33.5	2.2	35.7
3	23	10,000.1	16.6	6.9	49.3	72.9
3	24	9,999.8	8.3	2.5	4.7	15.5
3	25	2,087.6	0.0	2.7	56.2	58.9
3	26	6,810.8	9.1	18.5	155.0	182.6
3	27	2,459.2	0.0	14.0	0.0	14.0
3	28	10,009.8	3.3	16.2	22.4	41.9
3	29	9,961.5	1.8	47.5	120.0	169.3
3	30	36.4	14.3	18.8	150.9	184.1
3	31	30.2	0.0	91.5	46.9	138.4
3	32	3.2	0.0	0.0	343.6	343.6
4	1	7,915.4	13.4	23.2	173.2	209.8
4	2	38.6	0.0	131.1	108.0	239.0
4	3	3,772.4	0.0	43.9	153.3	197.2
4	4	3,494.3	0.0	14.6	77.1	91.7
4	5	3,237.1	0.0	0.0	119.7	119.7
4	6	1,923.3	0.0	0.0	62.9	62.9
4	7	10,000.6	0.0	26.4	104.8	131.3
4	8	9,999.3	0.0	20.1	98.8	119.0
4	9	9,186.3	0.0	19.9	102.4	122.4
4	10	9,999.6	12.8	22.1	162.2	197.0
4	11	2,928.1	0.0	6.0	10.5	16.5
4	12	9,969.4	0.0	38.3	147.6	185.9
4	13	9,999.3	0.0	57.2	143.7	200.9
4	14	9,986.4	0.0	51.7	69.9	121.5
4	15	462.0	0.0	11.4	154.8	166.2
4	16	7,986.0	0.0	70.1	177.7	247.8
4	17	8,235.1	7.0	95.6	155.9	258.5
4	18	8,751.0	0.0	34.3	124.7	158.9
4	19	2,068.7	0.0	22.7	99.6	122.3
4	20	7,179.7	0.0	38.3	82.5	120.7
4	21	8,460.9	8.4	61.1	108.9	178.5
4	22	9,067.9	0.0	28.3	127.1	155.4
4	23	9,356.6	0.0	57.1	127.3	184.4
4	24	1,921.5	0.0	25.7	89.8	115.5

Appendix 3.7 (page 1 of 2): Forest area conversion by road clearances, for each road class by basemap.

FOREST REGION	BASEMAP	BASEMAP AREA (ha)	ROAD CONVERSION (ha/10,000 ha)			TOTAL
			PRIMARY	SECONDARY	TERTIARY	
1	1	6,519.8	0	154	118	272
1	2	4,622.2	0	43	18	61
1	3	10,002.3	0	1	8	9
1	4	5,564.5	0	0	62	62
1	5	7,302.2	0	15	3	18
1	6	164.1	0	0	41	41
1	7	8,070.4	0	0	0	0
1	8	30.6	0	0	0	0
1	9	284.4	0	0	42	42
1	10	10,011.3	7	22	82	111
1	11	418.6	0	74	14	88
1	12	9,980.0	10	18	91	119
1	13	79.5	0	0	99	99
1	14	7,989.0	22	28	89	139
1	15	8,402.2	0	0	75	75
1	16	8,086.5	0	0	0	0
1	17	5,940.1	0	0	5	5
1	18	2,042.5	0	0	0	0
1	19	6,910.2	0	6	16	22
1	20	8,793.9	29	16	105	150
1	21	2,648.7	84	0	175	259
1	22	134.2	0	0	271	271
2	1	165.0	0	83	110	193
2	2	3,034.4	0	94	131	225
2	3	2,707.5	0	40	68	108
2	4	2,335.2	0	0	0	0
2	5	1,977.4	0	0	0	0
2	6	1,657.8	0	0	0	0
2	7	1,259.6	0	0	40	40
2	8	321.5	0	34	40	74
2	9	10,602.8	0	17	22	39
2	10	10,000.8	0	25	30	55
2	11	9,999.3	0	0	9	9
2	12	4,025.3	0	0	31	31
2	13	9,999.8	0	0	0	0
2	14	9,974.3	0	0	11	11
2	15	21.9	0	0	0	0
2	16	11,326.0	0	7	38	45
2	17	10,000.0	0	0	0	0
2	18	10,001.1	0	0	0	0
2	19	8,031.3	0	0	0	0
2	20	9,999.1	28	2	17	47
2	21	11,776.2	7	3	26	36
2	22	10,000.2	19	0	25	44
2	23	10,000.9	0	0	0	0
2	24	9,999.6	0	0	0	0
2	25	7,644.9	0	0	0	0
2	26	12,217.0	13	13	64	90
2	27	10,000.0	17	35	42	94
2	28	10,000.1	0	33	13	46
2	29	9,999.7	0	0	0	0
2	30	7,350.5	0	0	0	0
2	31	6,904.2	9	121	178	308
2	32	10,000.1	28	102	113	243
2	33	10,000.1	44	43	24	111
2	34	9,999.9	10	26	1	37
2	35	7,045.0	0	0	0	0
2	36	7,302.0	2	26	5	33
2	37	10,000.2	0	4	19	23
2	38	9,993.3	12	26	28	66
2	39	9,944.4	14	2	5	21

Appendix 3.7 (page 2 of 2): Forest area conversion by road clearances, for each road class, by basemap.

FOREST REGION	BASEMAP	BASEMAP AREA (ha)	ROAD CONVERSION (ha/10,000 ha) PRIMARY	SECONDARY	TERTIARY	TOTAL
2	40	5,941.1	0	0	10	10
2	41	8,094.3	0	20	37	57
2	42	9.9	0	155	103	258
2	43	68.9	18	110	39	167
3	1	55.7	0	0	45	45
3	2	9,998.2	0	37	32	69
3	3	9,807.9	29	17	67	113
3	4	6,605.7	35	0	52	87
3	5	9,536.6	17	19	108	144
3	6	0.1	0	0	0	0
3	7	6.7	0	0	0	0
3	8	1,177.9	0	21	61	82
3	9	23.4	0	122	229	351
3	10	8,749.3	0	75	127	202
3	11	9,931.0	34	63	94	191
3	12	10,000.4	34	53	123	210
3	13	7,936.5	21	95	175	291
3	14	970.3	42	0	34	76
3	15	10,000.1	0	73	61	134
3	16	1,700.4	0	0	8	8
3	17	9,999.6	29	54	94	177
3	18	7,452.3	0	37	90	127
3	19	7,140.4	0	47	90	137
3	20	1,964.5	0	0	0	0
3	21	9,999.5	0	67	2	69
3	22	10,000.1	0	67	2	69
3	23	10,000.1	42	14	49	105
3	24	9,999.8	21	5	5	31
3	25	2,087.6	0	5	56	61
3	26	6,810.8	23	37	155	215
3	27	2,459.2	0	28	0	28
3	28	10,009.8	8	32	22	62
3	29	9,961.5	4	95	120	219
3	30	36.4	36	38	151	225
3	31	30.2	0	183	47	230
3	32	3.2	0	0	344	344
4	1	7,915.4	33	46	173	252
4	2	38.6	0	262	108	370
4	3	3,772.4	0	88	153	241
4	4	3,494.3	0	29	77	106
4	5	3,237.1	0	0	120	120
4	6	1,923.3	0	0	63	63
4	7	10,000.6	0	53	105	158
4	8	9,999.3	0	40	99	139
4	9	9,186.3	0	40	102	142
4	10	9,999.6	32	44	162	238
4	11	2,928.1	0	12	10	22
4	12	9,969.4	0	77	148	225
4	13	9,999.3	0	114	144	258
4	14	9,986.4	0	103	70	173
4	15	462.0	0	23	155	178
4	16	7,986.0	0	140	178	318
4	17	8,235.1	18	191	156	365
4	18	8,751.0	0	69	125	194
4	19	2,068.7	0	45	100	145
4	20	7,179.7	0	76	82	158
4	21	8,460.9	21	122	109	252
4	22	9,067.9	0	57	127	184
4	23	9,356.6	0	114	127	241
4	24	1,921.5	0	51	90	141

APPENDIX 4: WORKSHOP PARTICIPANTS

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N.B. Forestry Canada is now the Canadian Forest Service

APPENDIX 5: OTHER POTENTIAL INDICATORS

Naturalness - Timber Management and Aesthetics

This naturalness indicator relates the degree of naturalness and aesthetics of a forest landscape to the extent of timber management in terms of total area dedicated to timber management activity. When a forecast is made, of 50 years into the future for instance, harvest-origin stands will shift, as they age, from a young unnatural class to the older, more natural class. A comparison of the total area of the two stand classes provides a gauge of forest naturalness and aesthetic value.

The expert approach to evaluating forest aesthetics contains two distinct views: the fine arts perspective, and the ecological perspective (Zube et al. 1982). Within the ecological approach it is assumed that natural, unmodified ecosystems are most highly valued (Smardon 1975). The public in the U.S. has been shown to favour an apparently natural forest landscape over modified landscapes (McCool et al. 1986). Timber management affects aesthetic values of the public in a number of ways. The sequential pattern, regular shapes, and small size of openings resulting from timber management are perceived as artificial by the public. A reduction in average stand size, and an increase in shape complexity of the remaining forest, results in a decrease of forest landscape naturalness.

Impacts of timber management on forest aesthetics depend upon geographic location, user-group, perception of naturalness (Ribe 1989, McCool et al. 1986), and silvicultural practices. These impacts are most acute at the time of management treatment (e.g. clearcut harvest), and they subside over time. Indeed, many boreal stands regenerated following clearcut harvest will eventually assume a very natural appearance, once a certain level of maturity has been reached. However, a quantified relationship between timber management and forest aesthetics, including the precise age at which a forest landscape recovers aesthetically following timber harvest, is unknown (Ribe 1989). Aesthetic perception of forest landscapes is specific to each forest region, and has not been a subject of significant research in Canada. Work is being undertaken currently in Ontario under the Tourism Guidelines Effectiveness Monitoring Program of the Ontario Ministry of Natural Resources (W. Haider, OMNR 1993, pers. comm).

Literature Cited

McCool, S.F., R.E. Benson and J.L. Ashor. 1986. How the public perceives the visual effects of timber harvesting: an evaluation of interest group preferences. Environmental Management 10:385-391.

Ribe, R.G. 1989. The aesthetics of forestry: what has empirical preference research taught us? Environmental Management 13:55-74.

Smardon, R.C. 1975. Assessing visual-cultural values of inland wetlands in Massachusetts. In: Landscape Assessment: Values, Perceptions and Resources, (Zube, E.H., R.O. Brush and J.G. Fabos, editors), pp. 289-318. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania.

Zube, H., J.L. Sell, and J.G. Taylor. 1982. Landscape perception: research, application and theory. Landscape Planning 9:1-33.

APPENDIX 6: METHOD FOR ASSIGNING DATA

Data was assigned to stands that were lacking data in the original dataset. It was assumed that stands regenerate back to the cover type of the WG that was in the highest proportion in the pre-cut stand. Yield curves do not exist for plantations in the Spruce River Forest. Age, height, and stocking were assigned to stands at conservative levels since all cutovers are not planted, and all plantings are not successful.

Assigning Working Group or Cover Type and Stand Attributes to Cutovers

Regenerating stand data was assigned to a cover type and FRI composition based on the WG or combined WG of pre-cut stands with largest cumulative area (Table A6.1). Stand attributes were assigned to cutovers as per Table A6.2.

Assigning Attributes to the Burn

The burn area in the Spruce River Forest from the burn in 1980 is not current in the database. The area has seeded in quickly, and the burnt area is regenerating well (Kromm 1993). The following stand attributes were assigned to the forest stands within the forest area burnt (current to 1985) (Table A6.3).

Table A6.1: Assigning Working Group or Cover Type to Cutovers

Pre-cut Stands	Regenerating Stand	
Dominant combined WG by area	FRI WG	Cover Type
Sb + Sw	Sb	Sp
Po + Bw	Po or Bw *	Po or Bw *

* WG with largest area proportion in pre-cut stands

Table A6.2: Assigning Attributes to Cutovers

Year of Cut	Regenerating Stand (1985)		
	Age (yrs)	Height (m)	Stocking
1982 - 85	0	0	0
1979 - 81	2	0	.7
1976 - 78	3	0	.6
1973 - 75	5	1	.7
1970 - 72	8	2	.7

Table A6.3: Assigning Attributes to the Burn (current to 1985)

Age (yrs)	Height (m)	Stocking	Working Group and Species Composition
5	1.0	1.0	as in pre-burn stand

APPENDIX 7: CONVERTING STANDS OF THE SPRUCE RIVER FOREST INTO COVER TYPES

Where:

Oc = Ce, La   C = all conifers   Hw = Po, Bw   Sp = Sb, Sw   Pine = Pj, Pw, Pr

(a) If WG = Sp:

If Sp ≥ 8, then type = Sp

Else Sp < 8,

If Pine ≥ Oc + Fb

and if Pine ≥ Hw, then type = Sp/Pine

If Hw > Pine + Oc + Fb, then type Sp/Hw

Else, then type Sp/C

(b) If WG = Pine:

If Pine ≥ 8, then type = Pine

Else Pine < 8,

If Sp ≥ Oc + Fb

and if Sp + Fb ≥ Hw, then type Pine/Sp

If Hw > Sp + Oc + Fb, then type = Pine/Hw

Else, then type Pine/C

(c) If WG = Fb:

If Fb $\geq$ 8, then type = Fb

Else Fb < 8,

and if Sp + Pine + Oc $\geq$ Hw, then type = Fb/C

Else, if Sp + Pine + Oc < Hw, then type = Fb/Hw

(d) If WG = Po:

If Po $\geq$ 8, then type = Po

Else Po < 8,

and if Sp + Pine + Oc + Fb $\geq$ Bw, then type Po/C

Else, if Sp + Pine + Oc + Fb < Bw, then type = Po/Bw

(e) If WG = Bw:

If Bw $\geq$ 8, then type = Bw

Else Bw < 8,

and if Sp + Pine + Oc + Fb $\geq$ Po, then type Bw/C

Else, if Sp + Pine + Oc + Fb < Po, then type Bw/Po

(f) If WG = Ce, then type = Ce

(g) If WG = La, then type = La

(h) If WG = Oc, then type = Ce

APPENDIX 8: CONVERSION TO NEW LANDSCAPE MATRIX CLASSIFICATION

1. Add a column for cover type to FRI stand listing.
2. Compare locally large stands to smaller surrounding stands.
3. If smaller stands are compatable according to cover type, and height and stocking are equal, then combine and type as cover type of large stand.
4. Maintain the FRI composition of the large stand.

APPENDIX 9: FOREST EDGE RULES

I. Hardwood / Softwood Edge Rule

If stand1 SW dominant and stand2 Hw dominant, then edge

(SW dominance occurs where summation of SW species proportions ≥ 5)

(HW dominance occurs where summation of HW species proportions > 5)

II. Height / Structure Edge Rule

1. Forest Edge Rule

If at least one stand is conifer dominant, and:

    If ht1 or ht2 ≥ 6m,

        and other ht < 6m,

        and ht difference ≥ 2m, then edge

    Else, no edge

If both stands hardwood dominant, and:

    If ht1 or ht2 ≤ 8m,

        and other ht > 8m,

and ht difference $\geq$ 2m, then edge

Else, no edge

2. Road Edge Rule

Assume:

(a) 1/4 to 1/3 of tertiary roads are scarified, and regain closed-forest condition within a short period.

(b) The vast majority of unscarified tertiary roads also regain closed-forest condition within a short period.

Total forest-to-road edge length = (total road length) X 2 - (non-forest edge length) - (young stand edge length)

Steps:

(a) Measure: total road length within a region = primary road length + secondary road length

(b) Calculate total edge length = (total road length) X 2

(c) Exclude non-forest edge, where, non-forest edge is non-forest types adjacent to either side of a road. A road section with a forest type on both sides has double the road edge that a road section with a non-forest type on one side.

(d) Exclude young stand edge, where young stand edge is:
for conifer $\leq$ 6m, for hardwood $\leq$ 8m

IV. Forest Cover Edge Rule

- TG is "typing group species" ie. dominant species of cover type
- "other species" is the second species in the cover type

If TG1 /= TG2, then edge

Unless:

1) TG1 and TG2 are: a) Po and Bw

or b) Sp, Bf, or Ce $\leq$ 50%

2) type1 and type2 are: Pine/Sp and Sp/Pine

3) Mixed wood

Both "other species" in type1 and type2 are generalized species (e.g., SpC and BwC),

and, within the FRI species composition of the two types there is a match between the WG in stand1 and at least one "other species" in stand2, and vice versa,

where compatable species groups are: a) Po and Bw

b) Sb, Sw, and Fb

and, the total correspondance between the species or species pairs that match is $\geq$ 6

e.g., stand1 = Sb4 Fb3 Bw3

stand2 = Bw4 Fb3 Sb2 Po1

- match between species in 1 and WG-related species in 2 is = 3

(matching Bw3 = 3 in stand1 to Bw4 + Po1 = 5 in stand2)

- match between species in 2 and WG-related species in 1 is = 5 (matching Fb3 + Sb2 = 5 in stand 2 to Sb4 + Fb3 = 7 in stand 1)

- the total correspondance is 3 + 5 = 8, and there is no edge

Else, if TG1 = TG2, then no edge

V. Stocking Edge Rule

If st1 or st2 > 0.6,

and other st < 0.6

and st1 - st2 ≥ |0.2|, then edge

Else, no edge